ROAD ENGINEERING

E. L. LEEMING,

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CONSTABLE AND COMPANY, LTD.

10–12 ORANGE STREET, LONDON, W.C.2

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by

E. L. LEEMING,

M.Sc.Tech., M.I.C.E., M.I.Mun.E.

(Engineer & Surveyor, Urmston Urban District Council)

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PREFACE TO THIRD EDITION

It is a curious state of affairs that causes progress in road engineering and development to move in phases, phases which are not unconnected with world economic upheavals and with war.

We are aware that the problems of road planning in a comparatively small country like Britain are not the same as those in vast continents like America or Africa. It is true also that we have a well-established system and variety of roads—some of them dating back to the days of Telford; in many cases, however, they are inadequate to withstand modern traffic conditions, yet the whole represents an enormous capital investment.

The passing of the Transport Act of 1946 involves the better co-ordination of road and rail traffic than hitherto. The urgent question of the improvement of our existing roads remains; there is also the crying need for motor roads to reduce road transport costs—a factor of great importance in our national economy, and the new motorways legislation will enable this type of development to make progress.

The economies in road construction and maintenance to be exercised in the years following the Second World War represent a passing phase; the road engineer is now required to exercise all his ingenuity to make improvements and to effect maintenance at low cost.

The principles of road engineering begun so well by Telford and Macadam remain, and our need today is to amplify these principles to meet the requirements of modern traffic.

This revised volume has been brought up to date so far as basic principles and latest practice are concerned; moreover, the latest American practice as noted by the author after a third tour (over a period of two decades), has been included. No attempt is made to describe in great detail such large-scale operations as carpeting with modern plant, etc.; suffice it to say that the original purpose of expounding the engineering principles of road-making has been retained throughout in this third edition, which it is hoped will be of increasing value to students and to others interested in this branch of Civil Engineering.

The author desires to acknowledge the valuable assistance received from his deputy, Mr. A. N. Potter, and several members of his staff in connection with the preparation of the diagrams.

Urmston,
January, 1952.

J. L. Leeming

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INTRODUCTORY

EARLIER TYPES OF ROADS

ONE of the earlier type of road pavements adopted in this country was the boulder paving, consisting of large irregular boulders 6 to 9 in. deep, possessing naturally large and irregular points, especially after wear had taken place. Other roads were paved with stone blocks which, however, were little better than the boulders. Small boulders or cobble pavements built within sea-shore boulders have been used very extensively, and are still in existence in many large towns today; they are roughly egg-shaped, and are placed on end, so as to give as great a depth as possible. Cobbles have also been used extensively for footpath work, but these are usually much smaller in size than those used for road work.

Sett paving of various kinds has superseded cobbles and boulders, and in many cases is giving excellent service today.

Earth and clay roads are still in use in remote parts of America, Africa and elsewhere, etc., where grading, harrowing, ploughing, scraping, etc., are carried on by machinery in a thoroughly scientific manner. Gravel roads are also used in like manner where conditions are favourable; newer developments in the form of soil stabilization have opened up a vast field for economical road development.

Examples of our early types of road construction are shown in Fig. 1.

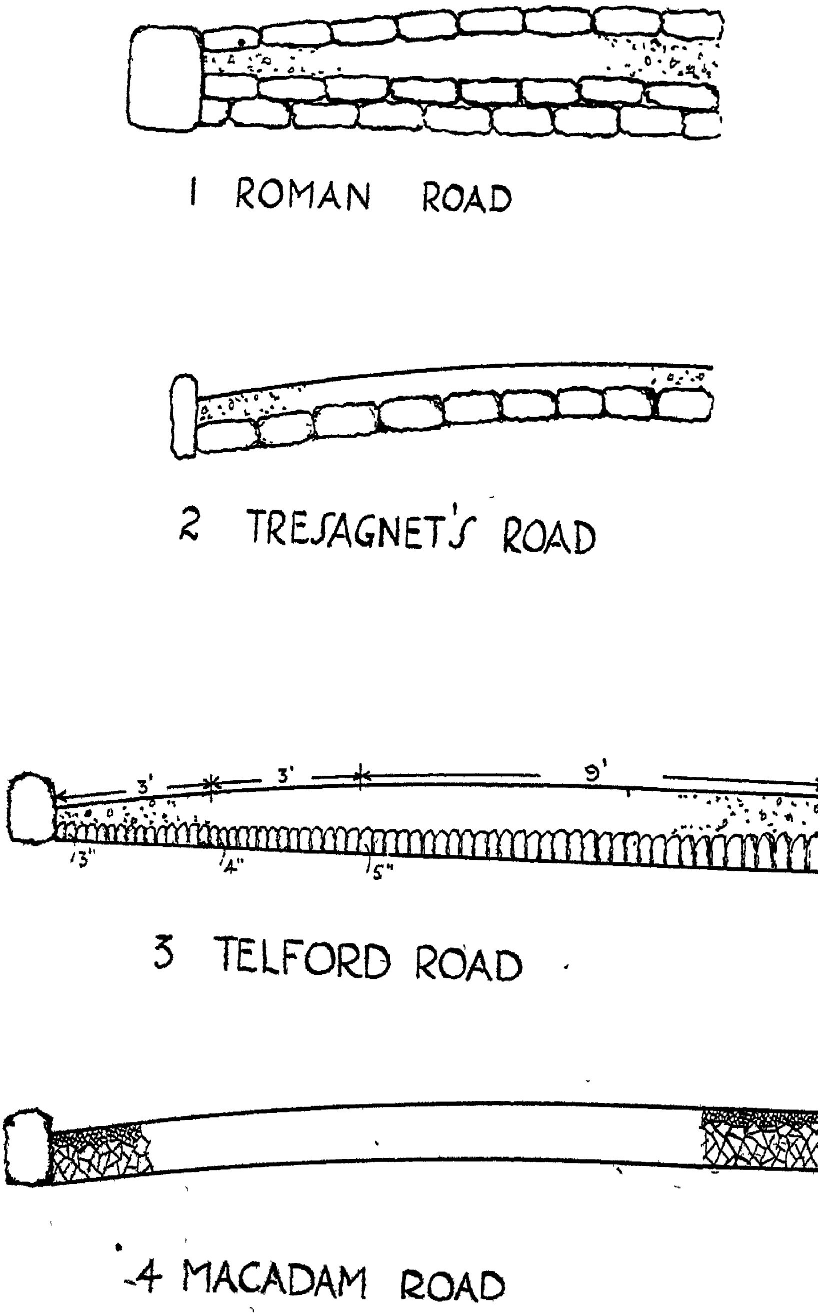

FIG. 1.—EARLY TYPES OF ROADS.

CHAPTER I

SUBSOILS, DRAINAGE, AND EARTHWORKS

BEFORE proceeding to deal with the problems that arise from the construction of the wearing surfaces of roads, some attention must be given to the subsoil upon which the structure of the road rests. The main difficulty in road foundations is to secure a uniform and firm condition of the subgrade which will enable heavy and concentrated loads to be carried without fear of structural failure. Subsoils vary in different districts and in different sections of the same road; it is important, therefore, to have a thorough understanding as to the methods of treatment for these subsoils to ensure reasonable consistency in its supporting value.

In view of the importance of this question, a technique has now been established for analysing the properties of different kinds of soil. Generally speaking, the area engineer will be familiar with the local conditions of subsoil, particularly in view of the experience gained in the process of laying sewers and other mains for which geological information should be fully recorded.

Supporting Value of Soils.

As the result of practical experience, it is well known that roads identical in type and design are not always equally successful, and this variation may frequently be traced to the differing support offered by the respective subgrades. A table is appended giving the supporting value of subsoils.

Type of soil.	Per sq. ft.
Made ground	½ ton
Soft clay	1 ton
Hard clay or loam	2–4 tons
Dry compact sand	2–4 tons
Dry course gravel	4–7 tons
Ordinary rock	4 tons and upwards
Hard rock	9 tons and upwards
Loose beds with filling	2 tons
Loose beds with concrete	3 tons

Although different types of soil differ from each other in their bearing capacity, they also vary in themselves under a diversity of conditions, such as altitude, geographical position, etc.

The chief factors that contribute to the loss of bearing power of a particular subgrade are :—

1. A friable condition of the soil.
2. The presence of water to saturation.

In the first case the ground may be consolidated by rolling, or it can be strengthened by the addition of broken bricks, breeze, brushwood, or some similar material that will combine with the existing soil and give it " body ". In extreme cases the whole bed of the road must be excavated and remade. It should be noted in this connection that a reinforced-concrete foundation will efficiently support the road-crust over any but the most severe conditions of subgrade.

Friability, as a condition, argues also lack of elasticity. This factor is elaborated in a series of tests of impact of pavements carried out by the Bureau of Public Roads, U.S.A.

It was found that the subgrades under test failed to return to their initial elevation when the pavements they supported were subjected to impact, whereas the concrete-slab pavement itself did not spring back after each blow. Each succeeding blow caused the slab deflection to increase, in ratio to the " looseness " or friability of the soil and also to the degree of water content.

In the limit, the subsoil ceases to offer any support and the slab acts as a beam. These tests do not conform absolutely to the conditions existing on actual pavements, but they have an application in the case of a subgrade which offers a varying or uneven support, as the consolidated portion will resist the stresses imposed upon it by the traffic and the " loose " portion will tend to deform to a greater or lesser degree. Obviously failure can be expected under these conditions.

There is a wide divergence of opinion as to the effect of water on subsoil, and there is considerable scope for research work in this connection.

One may assume, however, that the bearing power of most soils is not greatly affected by the addition of water up to the moisture equivalent—i.e. the percentage of moisture retained in the soil when subjected to a centrifugal force equal to 1,000 times the force of gravity—especially where the supporting value is uniform, but after a certain point, which varies with the nature of the soil, there is a rapid reduction in bearing power until complete saturation is reached, when it is of little or no value as a support.

Distribution and Effects of Pressure.

The usual practice of regarding the distribution of pressure from a wheel load as of pyramidical form does not apply in the case of

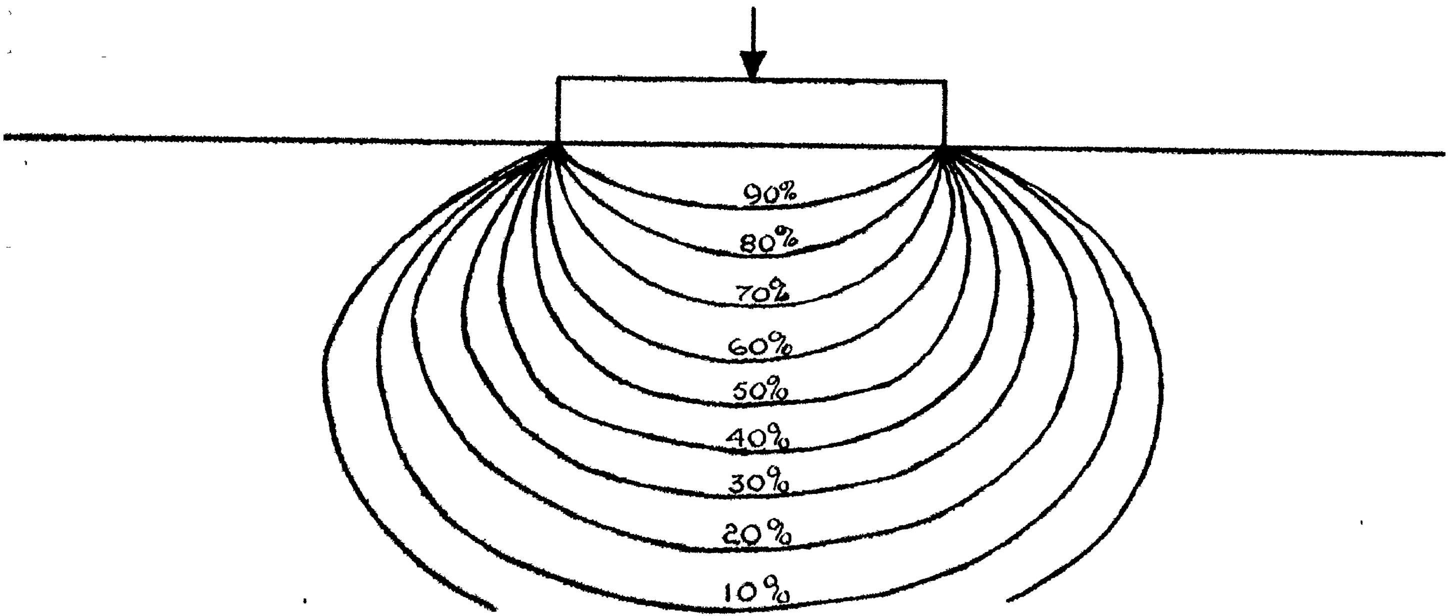

FIG. 2.—EARTH-PRESSURE DIAGRAMS, STRESS DISTRIBUTION BY ISOBARS.

roads constructed of concrete. It can be shown that the supporting value of the earth beneath the edge of the slab is zero. On the other hand, the supporting value of the subsoil beneath the centre of the

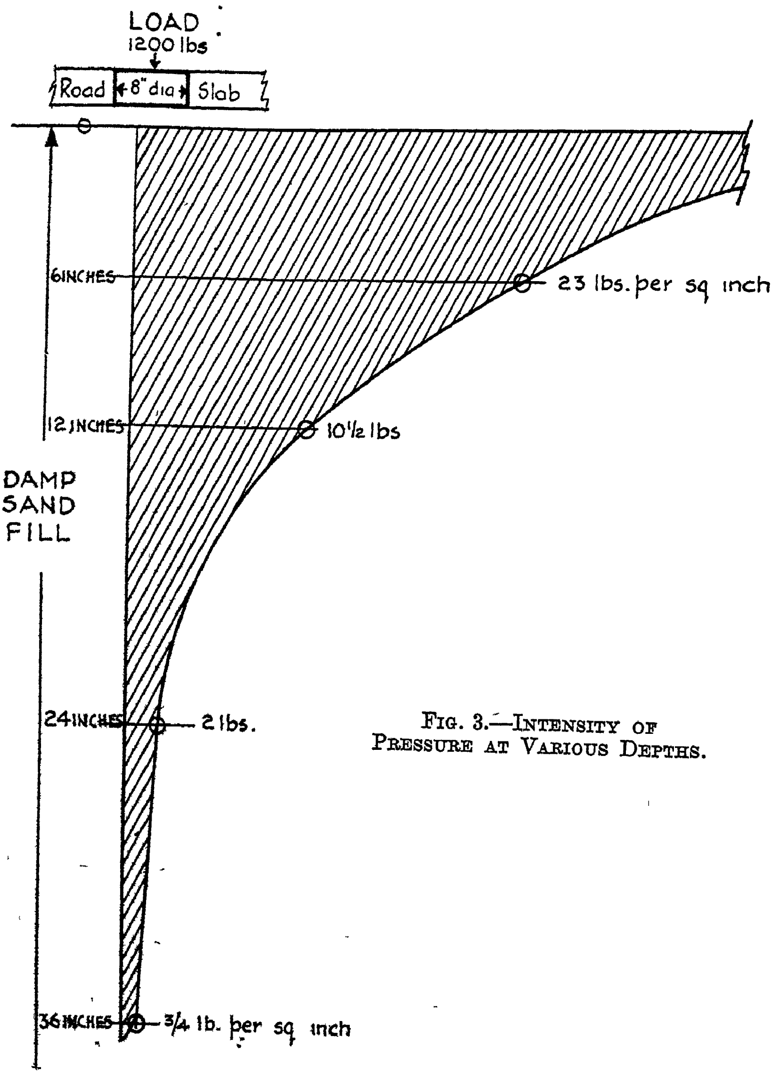

Fig. 3.—Intensity of Pressure at Various Depths.

lab is comparatively high under normal conditions. Fig. 2 shows he vertical stress distribution in the form of isobars—known as the ressure bulb: the stress is known as a percentage of the applied ressure. If pressure $P2$ is applied on surfaces AG and BE the bearg capacity of the medium is increased by an amount proportioned o $P2$.

Fig 3 illustrates the intensity of pressure at various depths beneath the base of the slab supporting the load.

The weakness of the subgrade at the edge of a slab necessitates special design by strengthening against cantilever action, or by carrying the concrete base beyond the edge subjected to traffic.

Tests carried out on 3-ft.-diameter slabs indicated a recovery to the original position after removal of the load. Under repeated loading, over a period of three days, the depressions decreased and the soil reached an apparently definite elastic limit.

Field tests may be made on soils using 3-ft.-diameter slabs, by means of a jack with pressure-dial supporting a loaded motor lorry.

It is of interest to note that bearing-power tests on hexagonal slabs give a higher result than tests on square slabs under similar conditions.

Comparative bearing power may be determined by compressing samples of the prepared and kneaded soil in a cylinder, the compression being noted at the respective loads.

The elastic limit of a damp soil is probably less than 1 lb. per sq. in.

The Goldbeck Pressure Cell.

An interesting apparatus deserving of mention here is the air-pressure cell originally designed by Mr. A. T. Goldbeck, for the purpose of measuring the pressure at the base of a slab or at the back of a retaining wall. The cell—a diaphragm connected by $\frac{1}{8}$-in. piping from an air-pressure cylinder—is placed beneath the slab in the required position. Electrical connections, by another pipe carrying the wires, are made between the diaphragm and an indicating light. Air is supplied to the diaphragm to balance the pressure on the underside of the concrete. As soon as this pressure is raised above the pressure of the concrete, the diaphragm is moved, an electrical contact broken, and the light extinguished. The pressure of the cell indicates the pressure of the slab on the subgrade at that point. By means of this cell, important results have been obtained regarding the variation of pressure at different points of a slab. In one case the centre of an 18-ft. slab registered no pressure owing to the arching of the concrete. In other cases it has been employed to determine the distance in front of a wheel-load at which the pressure begins to act on the subgrade.

Tests for Bearing Power.

In the early study of this subject the following tests were suggested to determine the bearing power of subsoils.

The samples consist of 0·2 cu. ft. of soil from the field, which is broken in a mortar with a rubber-covered pestle to pass a $\frac{1}{4}$-in. screen. The portion retained is considered as gravel, and is used

only for determining the mechanical analysis and bearing power; the remainder is passed through a soil-pulverizer consisting of two adjustable electrical driven rubber rolls.

The California Bearing Ratio.

This is used in American practice to measure the value of a soil as a subgrade. the test consists of determining the load/penetration relation for a plunger of 3 sq. in. area, which is forced into a sample of soil at optimum moisture content and again after soaking in water.

For comparison of penetration a material having 100% value is taken, and for design purposes the value at 0·1-in. penetration is normally used

An example quoted from the California State Highway Dept. is shown in the following table:

Penetration (in.).	Measured pressure (lb per sq. in.).	Standard pressure (lb. per sq. in.).	C.B.R. (%).
0·1	110	1,000	11
0·2	150	1,500	10
0·3	180	1,900	9
0·4	210	2,300	9
0 5	230	2,600	9

In designing, therefore, a C.B.R. value of 11% would be used.

Soil Surveys: Identification and Classification

Soil surveys now form an essential feature of the initial engineering survey in the location and design of an important highway; information regarding the nature of the soil and of subsoil water enables the road formation to be designed economically according to the nature of the subcrust upon which it is carried.

Identification Tests for Soils.

The standard tests used for identification of soils and the determination of their physical characteristics are as follows:—

Physical property.	Tests.
Grain size	Mechanical analysis (M.A.)
Plasticity	Liquid limit (L.L.) Plastic limit (P.L.) Plasticity index (P.I.)
Volume change	Shrinkage limit (S.L.) Shrinkage ratio (S.R.) Lineal shrinkage (L.S.)
Moisture capacity of soils	Field moisture equivalent (F.M.E.)
Resistance to flow of water	Centrifuge moisture equivalent (C.M.E.)

Mechanical Analysis.

The mechanical analysis of soils indicates the size and grading of the particles. The grain sizes of the particles retained on a No. 200 sieve are determined by sieve analyses; the sizes of the soil particles passing a No. 200 sieve are determined by hydrometer analysis—which is based on the fact that particles of equal specific gravity settle in water at a rate proportional to the size of the particle (this is known as Stokes Law).

An air-dried sample, passing the No. 10 sieve, is dispersed in water mechanically and is placed in a glass jar, water being added to increase the volume of the suspension to 1,000 c c.; the weight of soil

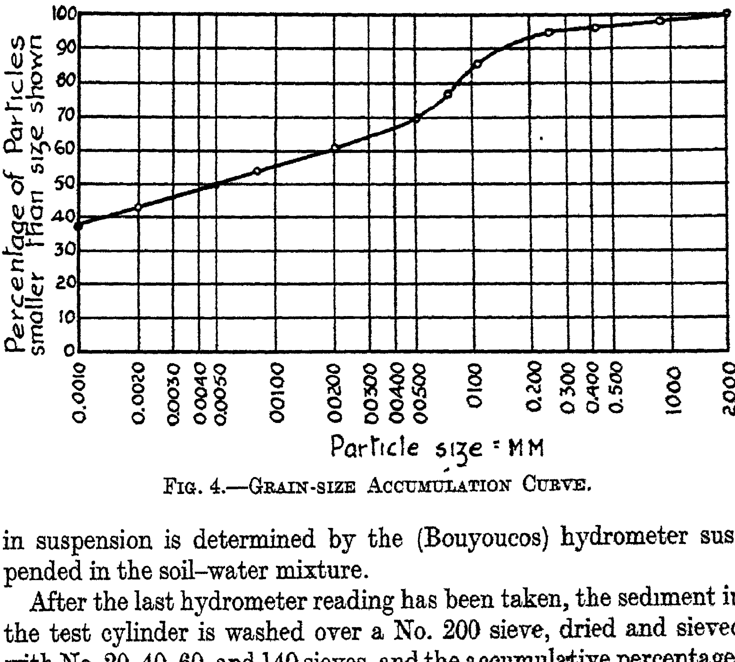

FIG. 4.—GRAIN-SIZE ACCUMULATION CURVE.

in suspension is determined by the (Bouyoucos) hydrometer suspended in the soil–water mixture.

After the last hydrometer reading has been taken, the sediment in the test cylinder is washed over a No. 200 sieve, dried and sieved with No. 20, 40, 60, and 140 sieves, and the accumulative percentages passing each sieve are recorded.

A grain-diameter accumulation curve is then plotted (Fig. 4).

Liquid Limit.

This is that moisture content expressed as a percentage by weight of the oven-dry soil at which the soil will just begin to flow when jarred slightly. At the liquid limit the cohesion in the soil is practically zero, with a definite but small shear resistance.

The soil sample is placed in a porcelain evaporating dish $4\frac{1}{2}$ in. diameter, shaped into a smooth layer about $\frac{3}{8}$ in. thick at the centre

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and divided into two portions by means of a grooving tool of standard dimensions. The dish is held firmly in one hand and tapped lightly ten times against the heel of the other hand. If the lower edges of the two soil portions do not flow together, the moisture content is below the liquid limit. If they flow together before ten blows have been struck, the moisture content is above the liquid limit. The test is carried out in most laboratories by a mechanical device.

Plastic Limit.

This is defined as the lowest moisture content, expressed as a percentage by weight of the oven-dry soil, at which the soil can be rolled into threads $\frac{1}{8}$ in. diameter, without the threads breaking in pieces, this "limit" is the moisture content at which cohesive soils pass from the semi-solid to the plastic state.

Plasticity Index.

This is the difference between the liquid limit and the plastic limit—the range of moisture content through which the soil is plastic.

If the plastic limit is equal to or greater than the liquid limit, the plasticity index is reported as zero.

Shrinkage Limit.

This limit is the moisture content, expressed as a percentage by weight of oven-dried soil, at which a reduction in moisture content will not cause a decrease in volume of the soil mass, but at which an increase in moisture content will cause an increase in volume of the soil mass.

Shrinkage Ratio.

The shrinkage ratio is equal to the bulk specific gravity of the dried soil-pat used in obtaining the shrinkage limit.

Thus

$$\text{Volume Change} = (W - S)R,$$

where W = moisture content, S = shrinkage limit and R the shrinkage ratio.

Lineal Shrinkage.

Lineal shrinkage is the decrease in a dimension of the soil mass, expressed as a percentage of the original dimension when the moisture content is reduced from an amount equal to the field moisture

equivalent to the shrinkage limit; it is usually expressed by the following formula :—

$$L.S. = 100\left(1 - \sqrt[3]{\frac{100}{C_f + 100}}\right)$$

where C_f is the change in volume from the moisture content at the field moisture equivalent to that at the shrinkage limit (Fig. 5).

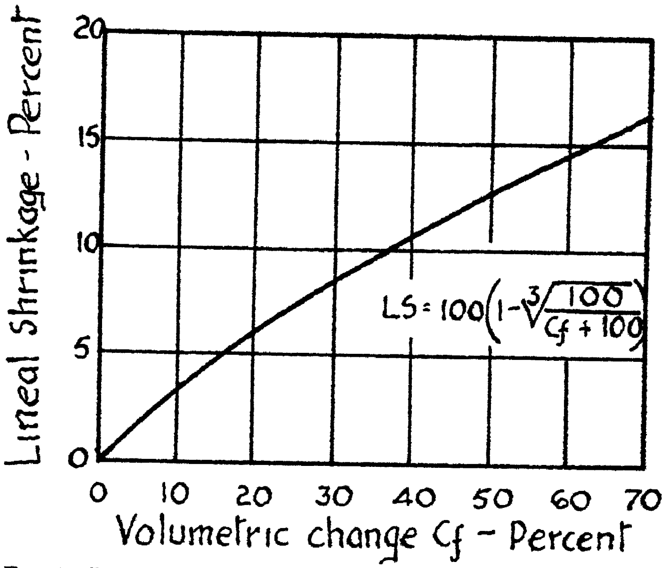


Fig. 5.—Relation of Volume Change and Lineal Shrinkage.

Field-moisture Equivalent.

This constant is defined as the minimum moisture content, expressed as a percentage by weight of oven-dry soil, at which a drop of water placed on the smooth surface of the soil will not immediately be absorbed, but will spread out over the surface and give it a shiny appearance.

The drop of water fails to penetrate the wet and smoothed soil sample (*a*) when the pores of non-expansive soils are completely filled; (*b*) when the capillarity of cohesion of less expansive soils is completely satisfied; and (*c*) when cohesive soils possess moisture in amount sufficient to cause the smoothed surface of the sample to become impervious. This impervious skin may occur at moisture contents far below those required to satisfy the capillarity of cohesive soils.

Centrifuge Moisture Equivalent.

This constant is defined as the moisture content, expressed as the percentage by weight of oven-dried soil, retained by a soil which has first been saturated with water and then subjected for one hour to a force equal to 1,000 times the force of gravity.

British Standard Specification.

A useful British Standard for methods of test for soil classification and compaction has now been published Special consideration has been given both to field tests of value in constructional work as well as to tests for use in soil-mechanics laboratories; typical forms are included for nearly all the test methods, to show how the results may be conveniently calculated and recorded.

Water-holding Capacity.

A sample of the soil contained in a box, 6 cm. diameter and 1 cm. high, the bottom of which is perforated with 150 holes, each $\frac{1}{32}$ in. diameter, is, after weighing, submerged in a pan of water on a brass triangle and heated for one hour. It is then blotted off, weighed, and the result compared with a dry soil.

Comparative Bearing Power.

Soils—coarse or fine—are first mixed by hand with water and moulded under an initial pressure of 30 lb. per sq. in. A brass cylinder of area 10 sq. in. is attached to the moving head of a 20,000-lb. (Universal) testing machine, which has a brass ring for confining the soil vertically and ensuring perpendicular loading, and also two 0·001-in. Ames dials for measuring the penetration. The weight of the soil and its volume before and after compression are noted, and the specific gravity and values for density under different conditions of moisture and initial compression are computed. There are also tests for determination of vertical capillarity, air shrinkage, and time of slaking. The above three tests provide an excellent indication of the strength of a soil under the various conditions of weather, loading, and natural drainage.

Extensive soil tests carried out by the Bureau of Public Roads at Washington yielded some interesting results; a summary of these is given below :—

1. The voids ratio determines the density of the subgrade soil; soils in their densest state make the most satisfactory subgrades.
2. The moisture content of a soil determines its suitability for subgrade purposes.

3. The porosity of a soil is a measure of the water-bearing capacity of the soil.
4. The stability of subgrade soils depends on the combined effect of cohesion and internal friction, the value of which helps to determine the deflection of a rigid or a flexible pavement.
5. Shrinkage of subgrade soils is caused solely by capillary pressure, and may be eliminated by maintaining a constant moisture content.
6. The permeability of a soil determines the rate at which it permits the percolation of water.
7. Adverse effect of capillary moisture in soils may be reduced by drainage only if ground-water level is lowered.
8. Expansion of soils caused by variations in moisture content should be controlled where possible.
9. The destructive action of frost is caused principally by the segregation and growth of ice-crystals.
10. Compression of a subgrade soil diminishes its permeability, but increases its density, and consequently its supporting power.
11. As the elasticity of soils increases, their stability for subgrade purposes diminishes.
12. The design of rigid pavements depends on the degree of uniformity of support furnished by the subgrade.

Considerable progress has since been made in soil classification, and some useful charts have been evolved.

The diagram in Fig. 6 is a right-angle soil chart which has been adapted from the handbook of the Portland Cement Association of America.

An example of the use of the graph to classify a soil containing 28% clay, 45% silt, and 27% sand is shown. At the intersection of the clay at 28 and the silt at 45, the soil is "clay loam" classification as shown in the diagram and schedule.

The proportions of sand, silt, and clay may be determined by sieve analysis or by inspection.

Curative Treatment of Subgrades.

Curative treatment to subgrades (or soil stabilization) with lime, Portland cement, or sand decreases the volumetric changes due to variation of moisture content, and increases the bearing area of plastic soils.

Sand and coarse materials effectively prevent the rise of capillary moisture above the water level, but tile-drains alone do not: when the tiles are laid at the side of the road they prevent the rise of the moisture under the bed of the road

Bearing power may be increased by reducing the moisture capacity of the soil, thus increasing the cohesion and internal friction.

The upward movement of wetted clay through stone or other ballast under traffic loads is completely arrested by interposing a layer of sand between them : the sand floats on the top of the clay, forming a kind of sand–clay mortar.

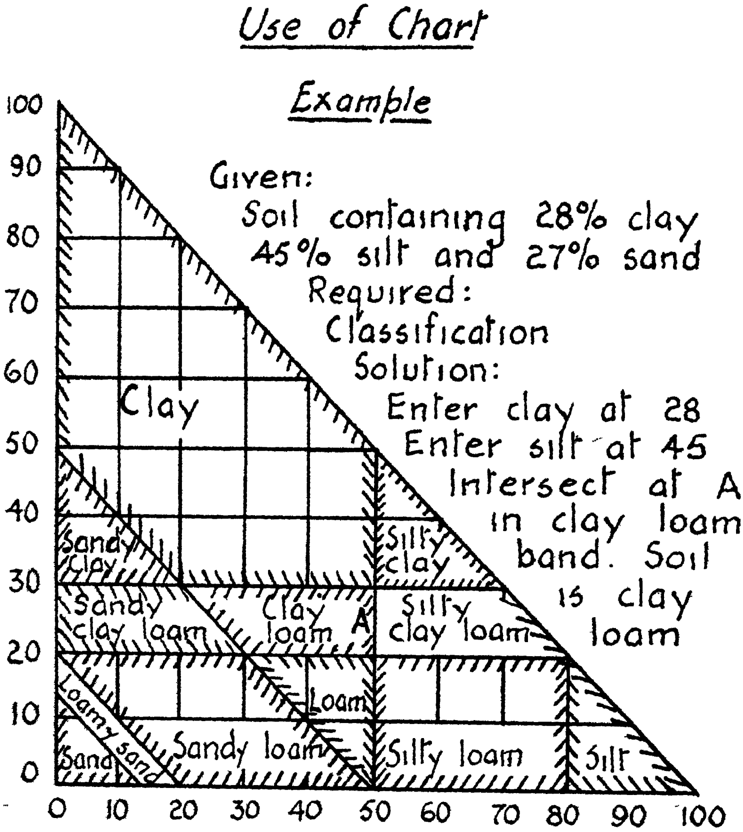


FIG. 6.—RIGHT-ANGLE SOIL CHART.

Clay subgrades swell and contract, lifting and then leaving the road-slab unsupported, so that it acts as a beam or a cantilever.

A higher moisture content beneath the centre and the edges will induce longitudinal cracks.

DRAINAGE

Subsoil Drainage of Roads.

Perhaps one of the first considerations in the engineering design of roads is the necessity to drain the subsoil or subgrade in order to

wise very wide roads is not usually performed by gullies in the centre of the highway, as the depressions in the surface would be dangerous to traffic.

Freezing of Soils.

Alternate freezing and thawing is an important factor in the destruction of pavements; excessive heaving occurs when the subsoil water or the capillary fringe level is high. Successive freezing often causes excessive heaving.

A road is likely to fail by frost-lift where the subsoil changes suddenly, as, say, from sand to clay. Large media, such as cinders, gravel, etc., prevent ice-segregation—such subgrade being uniformly and reasonably dry.

Frost effect is often more severe at the middle of a road than at the edges, where the earth and grass banks form a protection against it.

A longitudinal rubble or tile-drain with outlets is useful in minimizing the trouble (Fig. 8).

Prospecting Subsoil by Resistivity Methods

An interesting investigation for locating gravel deposits by the four terminal earth-resistivity methods (developed by Werner) was carried out in the U.S. by the Bureau of Public Roads in 1940.

The presence and depth of any material having different characteristics from the overlaying strata are revealed by the variation in resistivity values obtained.

The apparatus comprises: (1) the instruments containing the potential and current measuring devices; (2) the 200-volt battery box, and (3) the reels of wire: the potentiometer with a sensitive galvanometer has a maximum range of 1·10 volts. The potential electrodes consist of porous porcelain pots filled with a saturated solution of copper sulphate containing a coil of heavy copper wire. Current electrodes are heavy iron rods, 2 ft. × 1¼ in. diameter.

The porous pots are placed on the ground and the two electrodes at third points between them: thus a 20-ft. electrode spacing will yield data of material to a depth of 20 ft. This procedure is continued along a line of exploration: variations of resistivity indicate increasing or decreasing depths of gravel; sandy gravel has a high resistance.

This method, when checked by boring with auger, was proved to be reasonably accurate, and therefore saves time as compared with direct investigation by boring and excavation.

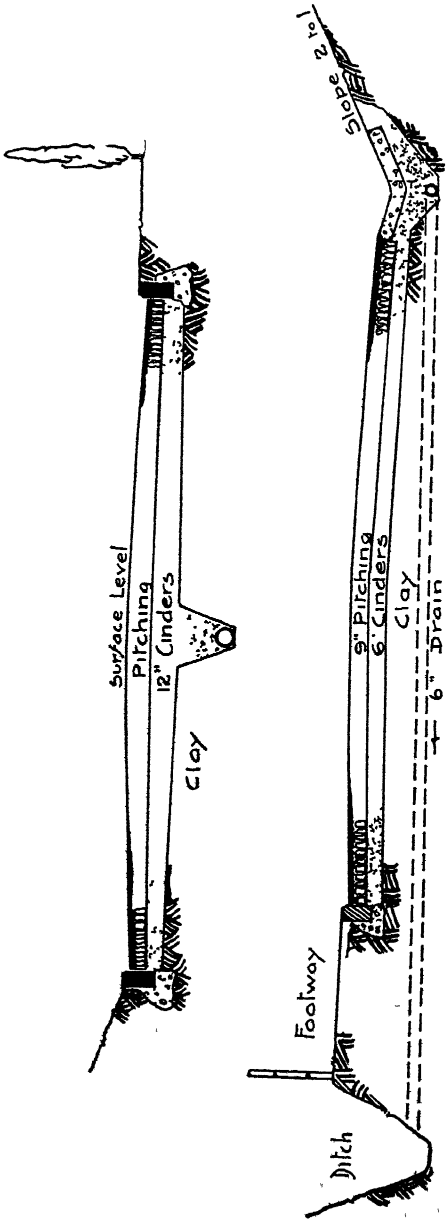


FIG. 8.—SECTIONS OF TWO TYPES OF FOUNDATION AND SUB-DRAINAGE

Embankment Construction—Consolidation

The construction of embankments carrying approach roads to bridges or across low-lying land requires great care, in order to avoid settlement, particularly uneven settlement due to varying depths of "fill". The material available requires careful study to determine the character of the soil filling; a wide variety of types of filling will be found satisfactory. Tests for mechanical analysis and physical constants should be applied: compaction tests carried out in the field, showing the dry and wet density and penetration resistance courses and the optimum moisture content.

If the soil filling is too dry it should be watered by a pressure distributor.

Consolidation may be carried out in layers 6–12 in. in depth, using for compaction the tamping action of a sheeps'-foot roller, the kneading action of a pneumatic-tyre roller, or the compression of a three-wheel roller. (Tests carried out at the Road Research Laboratory, Harmondsworth, show that the general efficacy in compaction of the rollers used increases in the order given, especially for gravel–sand–clay). Bulldozing to level out the filling also assists the consolidation. Further tests carried out showed that none of the rollers was able to compact effectively to a greater depth than 6 in.; for some soil conditions compaction was not fully obtained through more than 4 in. of the compacted layer. The frog-rammer used was able to compact more effectively both the granular and the clay soils, and to greater depths than the rollers.

Some margin from the optimum moisture content is permissible to secure good stability, providing the rollers are effective; if too wet, rolling will be less efficient. High-speed rolling is just as effective as rolling at slow speeds.

Given the control in construction and compaction of embankments by the use of the moisture–density curves and compaction data, there is no need to delay the construction of the carriage-way. There is often a tendency to use asphaltic or tar macadam on a filled base instead of concrete paving; if, however, the fill is laid with care, as described above, a concrete pavement may be laid with safety.

The side slopes of embankments should be sufficiently gentle to prevent the lateral flow of the materials.

It is desirable that when material is deposited, the better grain soil should be laid in the top layers up to the formation level.

A quick settlement of an embankment may be obtained by displacing the unstable material with the use of explosives or excessive watering or by excavation; this procedure is useful for swampy ground.

Stabilization by Chemical Treatment.

The condition of embankment soil may be improved by the addition of calcium chloride, sodium chloride, or a small proportion of bituminous material, to be used with suitably graded material the granular particles create the condition for stability; Portland cement may also be used with fine-grain soil, the proportion of the mixture to be determined by experiment. Bituminous stabilization is in its early stages of development, but sufficient information is available to say that a cold emulsion may be mixed by blading, after which consolidation is effected.

Natural Drainage

It is of importance to ascertain the natural drainage of the land across which a new road is to be laid down. A survey of existing water-courses, culverts, and surface drains over a wide area should be made in order to determine the best surface-levels and gradients for the road.

On sloping ground in open districts numerous outlets for water occur, and ample provision should be made for draining the flood-waters from the upper side of the road.

An economical method of conveying flood-waters across a secondary highway, in the form of a concrete slab acting as a ford, is dealt with in the chapter on Hill Roads.

In flat districts, difficulties are often presented by the comparatively high level of the water in the sluggish streams, which necessitates a design of road levels well above the surrounding land.

Under the Land Drainage Act of 1930 Catchment Boards * were formed and empowered to improve the land drainage over large catchment areas. These Authorities carry out drainage improvements and so relieve the flooding of highways, which often occur with monotonous regularity.

Ditches adjacent to the road should be made as wide as possible, thus preventing undue rise of the water-level in rainy seasons.

It does not follow that water-courses with a high water-level always transmit this level as subsoil water beneath the road; for the walls and bed of the water-course or ditch may have become sealed by a deposit of mud or fine material.

Effects of Climate.

The nature and variation of the climate have a most important bearing upon the life, and, consequently, upon the design of the road.

* These Boards have been succeeded by the more comprehensive Rivers Boards.

In the case of a dry climate the bearing-power of the subsoil will, obviously, be greater than that under wet climatic conditions. Also dry, cold weather is much less injurious to road-crusts than mixed cold weather, with consequent serious frost upheavals and disintegration.

Generally speaking, consistently wet weather is the most detrimental to the economical maintenance of roads; this is an unalterable difficulty, and one which can be countered only by giving more studied attention to the question of subsoils, water-levels, and drainage.

CHAPTER II

BRIDGES, CULVERTS, AND RETAINING WALLS

It is not within the scope of this book to deal with the question of the treatment of bridges; it is only proposed, therefore, to outline general conclusions regarding surfacing and probable impact or stresses likely to be encountered in bridge work, and also the considerations for safe approaches, vision, and vertical curves.

Paving Suitable for Bridges.

To be suitable for bridge work a paving must possess :—

(*a*) Low tractive resistance.
(*b*) Smooth wearing qualities.

The following are five types of paving which conform to these requirements. These refer to streets or suburban roads :—

1. Asphalte, including bituminous macadam.
2. Wood blocks.
3. Dressed granite cubes.
4. Concrete.
5. Rubber blocks.

The two first-mentioned possess elastic qualities which have the effect of resisting impact under traffic. Bituminous macadam is well suited for many bridges on country roads.

As a general rule it is advisable to reduce the thickness of the road slab to the smallest permissible dimensions in order to reduce the dead load on the bridge.

Concrete paving is decidedly the most suitable in this capacity, because it forms a wearing surface as well as a stress member. An allowance must be made for the wearing surface in addition to the thickness computed for the bridge stress : pre-stressed steel is now being used with advantage in reducing weight.

Small granite cubes, laid on concrete or reinforced concrete, form a reliable wearing surface without the dead weight on the bridge that would follow from the use of the larger setts. The jointing of these setts may be done with cement grouting, and in this case the setts may form part of the compression section of the beam slab.

A bridge-paving which has been employed with reasonable success under heavy traffic conditions, consists of rubber blocks $1\frac{1}{2}$ in. thickness, suitably pegged to a wooden decking by means of $\frac{3}{8}$-in. ears,

and three countersunk holes which are filled with asphalte. The anticipated life of this paving is about four years, although here and there some loosening of the blocks under traffic may occur, and necessitate renailing

In estimating the probable impact on the highway of a bridge it is essential to distinguish between live load and impact.

It has been stated by an authority on this subject, Prof. C. E. Inglis, that in the case of a 20-ft span of steel joists carrying motor lorries travelling at the rate of 20 m.p.h., the increment of stress, assuming no jolting, was only 3 or 4 %, and the application of load was comparatively sluggish. The percentage allowance for impact should clearly be a function of the span as in railway bridge design.

Other facts which should be considered are the nature and speed of the load and the natural period of vibration of the bridge or bridge members.

A reference to the impact tests in Chapter XXV will indicate the allowance which should be made for impact from motor lorries for a 2-in. drop or obstruction.

In an article in *Engineering News Record*, Mr. W. Whited dealt with this question of impact on bridges in detail. He stated that in his opinion there are two definite impacts on bridges—when the wheel strikes an obstacle and when it jumps off the obstacle—and suggests that the impact allowance, based on a 3-in. obstruction, should be two-thirds the sprung load at 15 m.p.h., and 0·8 for a 4-in. obstruction, so that an allowance of two-thirds the sprung load on any wheel, applied at whatever point of the bridge floor will give a maximum stress in the given member, represents a sound basis for computing impact.

Reinforced concrete can be used to advantage to strengthen bridges constructed to meet only the requirements of a previous age, and render them sufficiently strong to carry modern traffic.

A "carpet" of bitumen has been used successfully in the States, to strengthen plank road bridges, the elastic properties of the bitumen being of special value in this particular.

Standard Loads for Highway Bridges.

The Ministry of Transport has issued details of the standard load which will produce the maximum stress in any bridge member, providing that in any train of loads there shall not be more than one engine per 70 ft. of the span of bridge, and that the distance between the centre lines of two adjacent trains of loads is taken as 10 ft.

The actual loads on the bridge include an engine weighing 20 tons and drawing three trailers 13 tons each, as shown in Fig. 9. A

further 50% allowed for impact increases this weight to 30 tons fo the engine and 20 tons for each trailer. It will be understood, how ever, that this standard might be regarded as rather stringent fo country areas, and perhaps too little for some manufacturing centres the restriction of heavy traffic to principal roads will largely solve thi question

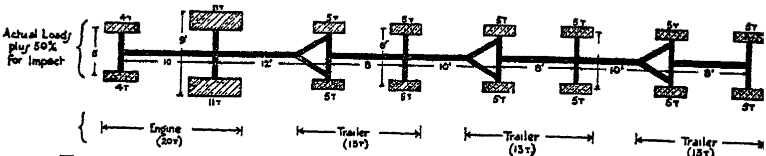


FIG 9.—STANDARD LOADS FOR HIGHWAY BRIDGES. (MINISTRY OF TRANSPORT.)

The series of loads is as follows .—

	Axle loads (tons).	Distance from front axle (ft.).	Width between wheels (ft.).
Front axle engine	8	0	5
Rear axle engine	22	10	9
1. Trailer front axle	10	22	6
1. Trailer back axle	10	30	6
2. Trailer front axle	10	40	6
2. Trailer back axle	10	48	6
3. Trailer front axle	10	58	6
3. Trailer back axle	10	66	6

The following appeared under the heading of "Highway Bridges" in the Report on the Road Fund, 1921–22, issued by the Ministry of Transport; the questions raised are still of great importance :—

"A large number of schemes have been under consideration for the improvement, strengthening, or reconstruction of highway bridges, many of which fall considerably short of modern traffic requirements—witness the warning notices displayed on the majority of these structures in the more remote parts of the country.

"It is obviously desirable for a uniform standard of strength to be applied to bridges on all the principal highways, and with this end in view a standardized loading for highway bridges has been prepared—see the relevant diagram. The aim has been to ensure that any bridge, towards the cost of which a grant is made or a loan recommended, shall be so designed as to carry any traffic which may come on the road, so that no restriction need be imposed on the use of the bridge. In deciding upon this

A cheap form of culvert now used extensively abroad is the corrugated rustless pipe made from an alloy of iron, copper, and molybdenum; this culvert is particularly strong by reason of the corrugations, and may frequently be used without the additional strengthening of a concrete surround.

Estimation of Run-off.

In the calculations to determine the size and capacity of surface water-pipes and culverts, it is usual to adopt the Ministry of Health "run-off" formula for the purpose.

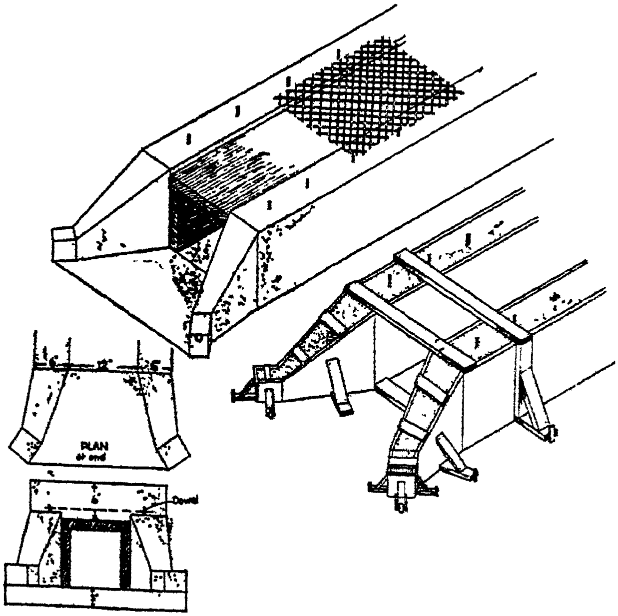


FIG. 11.—DIAGRAM SHOWING CONSTRUCTION NECESSARY FOR BUILDING A SQUARE CONCRETE CULVERT.

The rainfall rain-off R is determined from either of the following formulae :—

1. $$R = \frac{40}{T + 20}$$

where the time of concentration T is greater than 20 minutes, or

2. $$R = \frac{30}{T + 10}$$

where T is between 5 and 20 minutes.

Then $$Q = 60{\cdot}5 \times R \times A,$$

where A = acres of (equivalent) impermeable drainage area.

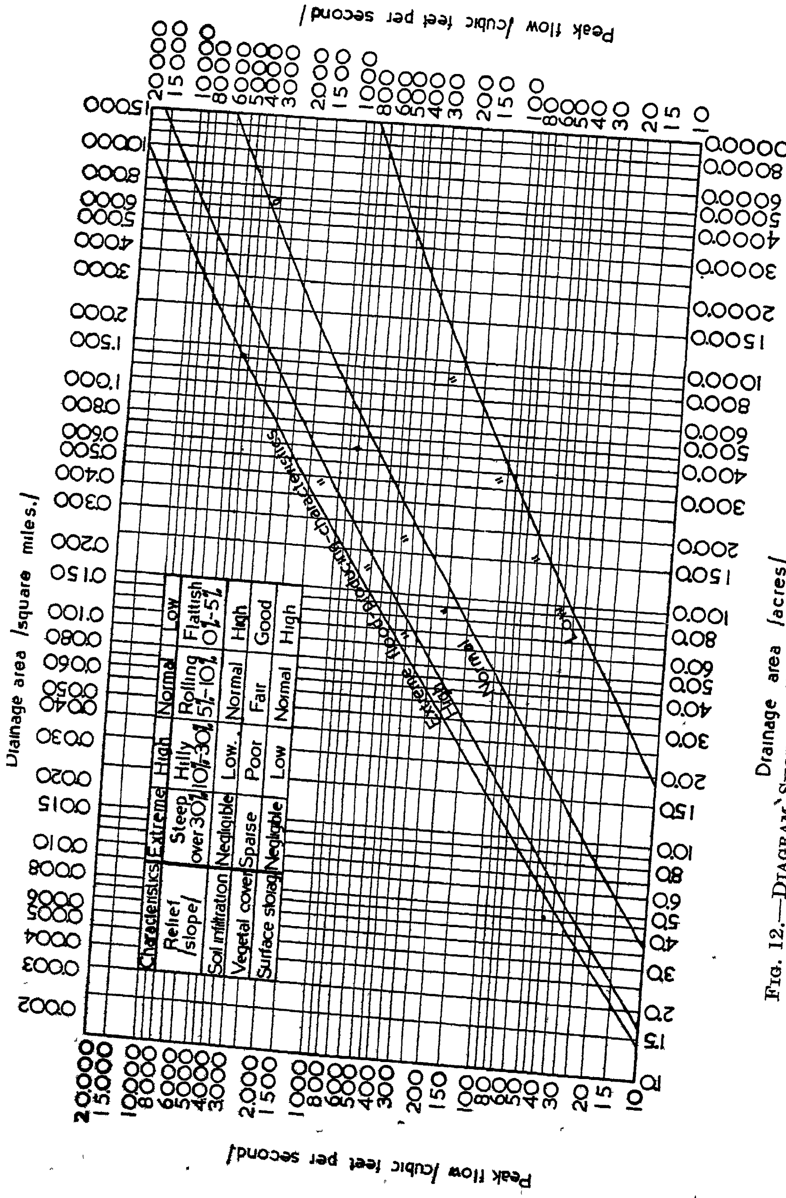


FIG. 12.—DIAGRAM SHOWING "RUN-OFF" FOR EXCEPTIONAL RAINFALL.

An important point in regard to camber is its influence on the wear of the road itself. On lighter-trafficked and the narrower roads the tendency is to travel on the middle of the road; a high crown will encourage this habit. It is clear that the reduction of camber with the modern road surface is the best way to prevent vehicles seeking the crown.

Another feature of wear on a well-cambered road is that caused by the greater weight on the inner wheels; correspondingly driving adhesion is reduced on the outer rear wheel. The result of this may well cause corrugations or disintegration of the road crust or skidding under "greasy" conditions; it is easy to skid a vehicle under these conditions by endeavouring to turn quickly towards the centre of the road or by braking suddenly

Cross-falls for Different Types of Paving.

Suitable cross-falls or cambers for various kinds of road surfaces, but with some headfall are given in the following table :—

Type of road.	Average cross-fall.
Water-bound macadam	1 in 24
Tar macadam	1 in 30
Bituminous macadam	1 in 36 to 1 in 48
,, asphalte, on concrete	1 in 48
Sett paving on concrete	1 in 48
Concrete paving	1 in 60 to 1 in 72

A cross-fall of 1 in 72 may even be reduced to 1 in 96 (or ⅛ in. per ft.) where the drainage is satisfactory and where no settlement is anticipated. With these flat cross-gradients the centre may be rounded slightly, although this is scarcely discernible.

The Parabolic Camber.

The parabolic camber is convenient for many road surfaces where the channels are level. The shape gives cross-falls between points as follows :—

1. Crown height	0%
2. Point ¼D.*	6·25% (below (1)
Fall between 2 and 3	18·75%
3. Point ½D.	25%
Fall between 3 and 4	31·25%
4. Point ¾D.	56·25%
Fall between 4 and 5	43·75%
5. Channel	100%

* D. = half width.

Sections of a parabolic camber are shown in Fig. 17.

Latest practice shows that for roads with four or more lanes it is

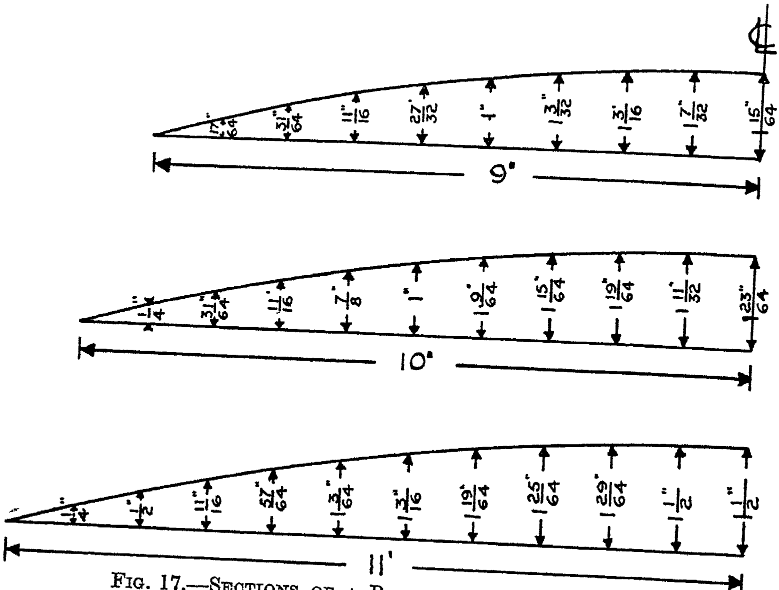


FIG. 17.—SECTIONS OF A PARABOLIC CAMBER.

desirable to provide a steeper slope on the outer lanes to assist the flow of water from the other lanes.

This is provided in the parabolic section, but an alternative would be to have different cross-gradients for each lane.

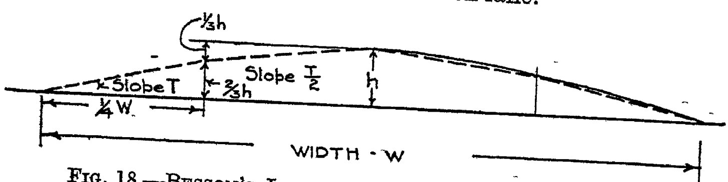


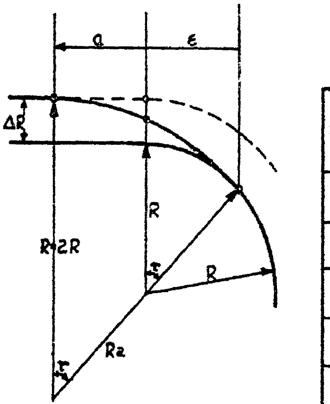
FIG. 18.—BESSON'S IMPROVED SECTION FOR CAMBERED ROADS.

Besson's Camber.

This camber is based on the principle that the point half-way between crown and channel should have a level of two-thirds the crown height; thus the gradient between mid-point and channel is twice the gradient between mid-point and crown. With this method the crown is slightly more pronounced and the slope near to the channel is more acceptable for traffic than the steeper slope of the parabolic section (Fig. 18).

If this curve is used, it is important to avoid the appearance of a kink, and some merging or adjustment between the two is necessary.

For main-road work the circular curve should be at least 500 ft.



Radius of Horiz curve R feet	Shift ΔR feet	a feet	τ min grad
1312	8 20	146 49	26°
1476	6·56	139 04	22°
1640	4·92	126 97	18°
1804	4 92	133 17	17°
1968	{3 28}	{113·61}	{13°}
2132	{3 28}	{118·24}	{13°}

When the radius of horiz curve R is between 1312 32 feet {min} and 1804 44 feet, an arc of radius · 2R should be inserted between the straight line and the actual arc of radius R The shift · ΔR

$$a = \sqrt{(2R - \Delta R)\,\Delta R}$$

FIG. 19(*a*).—THE COMPOUND CURVE (GERMAN AUTOBAHN).

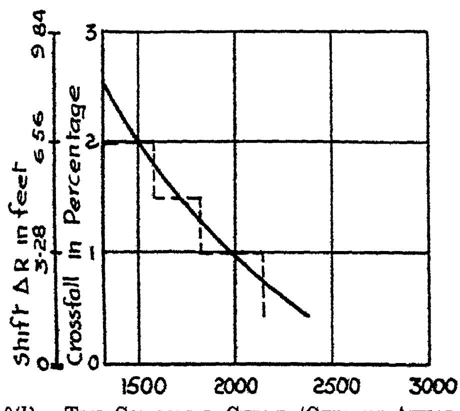


FIG. 19(*b*).—THE COMPOUND CURVE (GERMAN AUTOBAHN).

long for a deflection angle of 5°; where transitions are employed the curve should increase 100 ft. for each decrease of 1° in the deflection angle.

If it is desired to insert a transition curve between two circular curves, this can be done by introducing a spiral curve, as shown in

Fig. 20; it will be seen that the common radius line of the two circular curves bisects the spiral.

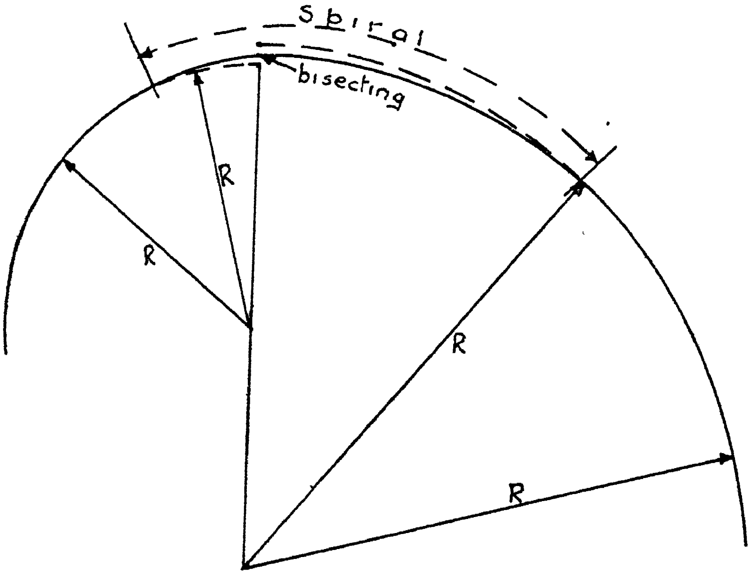


Fig. 20.—Diagram Showing Two Curves Joined by a Spiral.

2. *Simple Parabolic Curve.*

The properties of the parabolic curve make it suitable for transition and widening purposes.

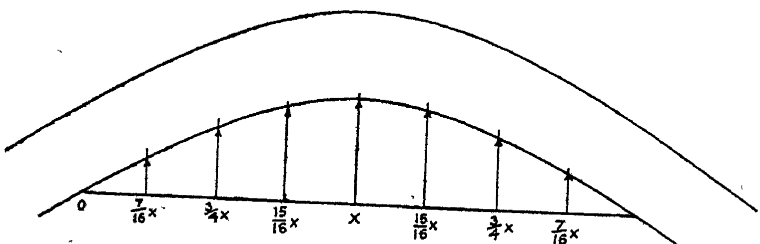


Fig. 21.—Use of Parabolic Curve for Improvement of Bends.

As will be seen from the diagram (Fig. 21), the curve which begins almost as a straight line increases its curvature gradually to the middle point of the curve, thus providing its own transition.

Taking a base line joining the two tangent points, easy vertical ordinates are readily erected by dividing the line into eight parts; the height of the second ordinate is three-quarters of the middle

ordinate—the same condition as for a parabolic cambered road. For small angles of deflection the parabola for a small range is more adaptable for use than the circular curve. Polar deflections in the parabola from the tangent point are directly proportional to distance x.

The equation for a simple parabola is $y = mx^2$, where m is a constant.

The formula for the cubic parabola is

$$y = \frac{x^3}{3m^2}$$

which for small angles is similar to the spiral.

3. *The Spiral Curve*

The spiral curve has become increasingly popular, in recent years, for transition work. The general equation is $\lambda = m\sqrt{\phi}$, where λ is the length of curve and ϕ the external tangent or "spiral" angle, i.e. the angle between the tangent at point of origin and the tangent at polar point; $m = \sqrt{2RL}$, $R =$ radius.

Since RL is constant, R must be inversely proportional to L.

Also $$Y = \frac{x^3}{6RL} \text{ for small angles.}$$

Prof. Royal-Dawson shows in his book on "Curve Design" that the equation $y = \dfrac{x^3}{6RL}$ applies for small angles to the spiral or clothoid curve, the lemniscate or the cubic parabola and that $X = L$ for very small angles.

A useful formula for the spiral curve is :—

$$\theta = \left(\frac{l}{l_s}\right)^2$$

where θ_s is the full spiral angle, θ the angle between the initial tangent and any chord K, $l_s =$ length along the full spiral, $l =$ length along the spiral for any chord, K.

It is convenient to arrange ten equal chords along the spiral; then the values of θ for each point on the curve will be as follows :—

$$\left(\frac{l}{l_s}\right)^2 \theta_s = \left(\frac{1}{10}\right)^2, \left(\frac{2}{10}\right)^2, \left(\frac{3}{10}\right)^2 \ldots \times \theta_s$$

and so on to unity.

Thus $\theta = 0{\cdot}01\ \theta_s$, $0{\cdot}04\ \theta_s$, $0{\cdot}09\ \theta_s$, $0{\cdot}016\ \theta_s$, etc., for points 1, 2, 3, 4, etc., up to 10, when $\theta = \theta_s$.

The properties of the spiral may be described as follows :—

1. Offsets y from initial tangent vary as the cube of L, the length of the spiral.
2. Spiral angle θ, varies as L^2.
3. Deflection angle ϕ, varies as L^2.
4. Degree of curve, D, L_s varies directly as L,

$$D = \frac{L}{L_s} D_c$$

where D_c = degree of curvature (of circle).

5. Spiral bisects the "shift" very nearly; thus the offset from the circular curve or tangent to midpoint of spiral is ½ shift P very nearly.

4. *Bernoulli's Lemniscate.*

This curve represents a French method of effecting transitions at bends or junctions. It resembles the spiral and the parabolic curves, and by some engineers it is considered superior to both; the author has used the curve since 1923. A fundamental property of the lemniscate (Fig. 22) is that the tangent at any point makes an angle with the polar ray, ρ, double the polar angle α and it follows that the angle between the two tangents is equal to 3α.

The formulæ for the lemniscate may be written :—

$$\rho^2 = C^2 \operatorname{Sin} 2\alpha$$

or

$$\rho = 3r \operatorname{Sin} 2\alpha$$

$$\rho = C\sqrt{\operatorname{Sin} 2\alpha}$$

The limiting value for α is 45°, which is always the angle between the tangent line at origin OA and ρ when its value is a maximum as at OB, Fig. 22.

In the example shown the angle of deviation Δ is 90°, between two roads connected by two symmetrical lemniscate curves.

The length of OA and DA are selected, having in mind to make the curves as great as practicable.

The angle α is clearly $\frac{45^\circ}{3} = 15$.

The length of the polar ray for $\alpha = 15^\circ$ may be determined by calculation for one side of triangle OCA or by geometrical construction by drawing from O and from D to intersect at C.

Knowing the value of ρ for a given value of α the constant C may be determined :—

$$C = \frac{\rho}{\sqrt{\sin 30^\circ}}$$

In this example $C = OB$; C is the length of the axis of the particular lemniscate.

If the theodolite is set up at point O the various polar ray lengths for different angles will give the points on the curve between O and C: this procedure is repeated at D and curve DC defined from the same dimensions.

For large curves with polar rays of 200 ft. or more, tacheometry may be employed with advantage; alternatively, the curve may be set out by offsets from the tangents.

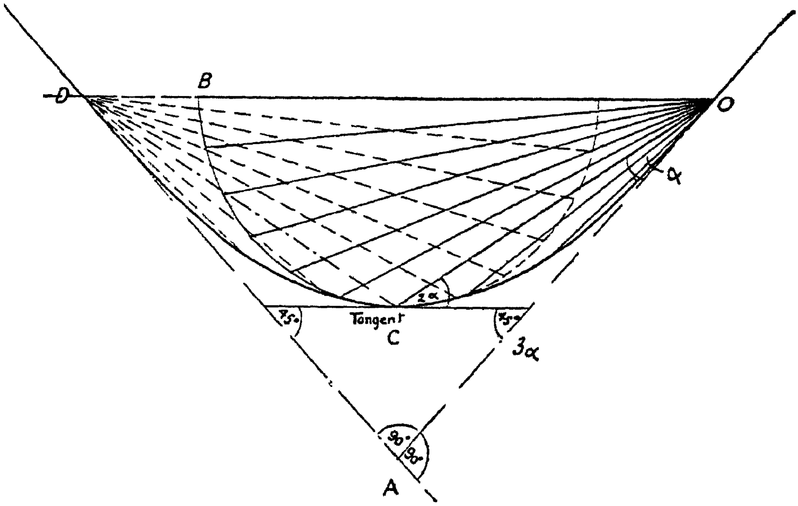


FIG. 22.—BERNOULLI'S LEMNISCATE FOR ROAD CURVES.

SELECTION OF TRANSITIONS

The question of the selection of a spiral or lemniscate transition curve has been dealt with in some detail in publications by Prof. Royal-Dawson and Mr. H. Criswell. As previously mentioned, there is little difference between the two curves, especially within a limited range of deflections, and, like Prof. Royal-Dawson, the Author prefers the lemniscate, which he has employed with advantage on several occasions; also for the simple parabolic curve, small deflections are similar to the other two.

The "Unit Chord" and "Speed Chord" System.

A brief description of this method of setting out the lemniscate curve, devised by Prof. Royal Dawson, is of interest. He takes a Unit of Measurement as the Polar Ray whose deflection is sixteen minutes.

The "Speed Chord" formula is given as $11{\cdot}4\ C^2 = V^3$, where C is the Unit Chord in feet and V the speed in miles per hour.

Thus, given the design speed, the Unit Chord can be determined; with the lemniscate used as a transition to the mid-point of the curve the polar (or deflection) angle is equal to $\frac{\Delta}{6}$, where Δ is the angle of deviation.

If the "Unit Chord" is taken as One Unit, the radius value, R, at the end of the first chord is always 35·81 units, at the second 17·91, at the third 11·94 units, and so on. The deflection angles progress by using the square of the number of the chord as a multiple of the first angle; thus we have, $16' \times 2^2 = 1° \ 4'$, $16' \times 9 = 2° \ 24'$, and so on.

This procedure is satisfactory for both the spiral or the lemniscate up to about 4°, after which some slight correction is needed.

In the case of the "Speed Chord" formula, a speed of 20 m.p.h. will give approximately 25 ft., and for 30·5 m.p.h. 50 ft. for the "Unit Chord".

Selecting the Length of the Transition.

The question of selecting the length of the transition and determining whether to make it wholly transitional or to interpose it with a circular curve must be left to the individual engineer to decide. The use of the celluloid lemniscate curves designed by Prof. Royal-Dawson are extremely useful in the drawing-office for this purpose.*

Certain cases will demand part circular treatment in order to retain a greater radius value to meet the limit of superelevation.

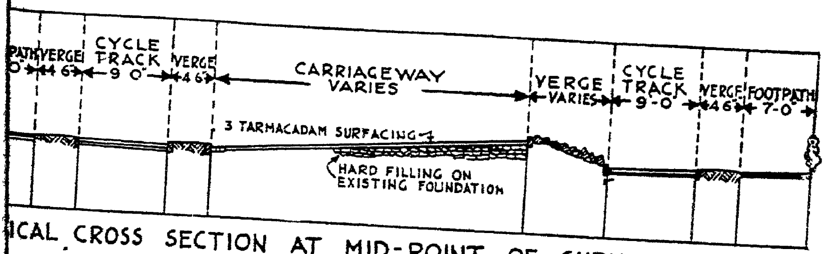
On the other hand, a complete transition may justify a steeper rate of banking for the comparatively short distance at the centre of the curve where the radius value is low. This procedure was adopted by the Author in the case of Lostock Road, Davyhulme, where the maximum crossfall was 1 in 10.

This curve is some 300 yd. in length with an angle of deviation of 45°. The outer and inner kerb lines were set out independently using polar rays and angles by use of the theodolite (Fig. 23).

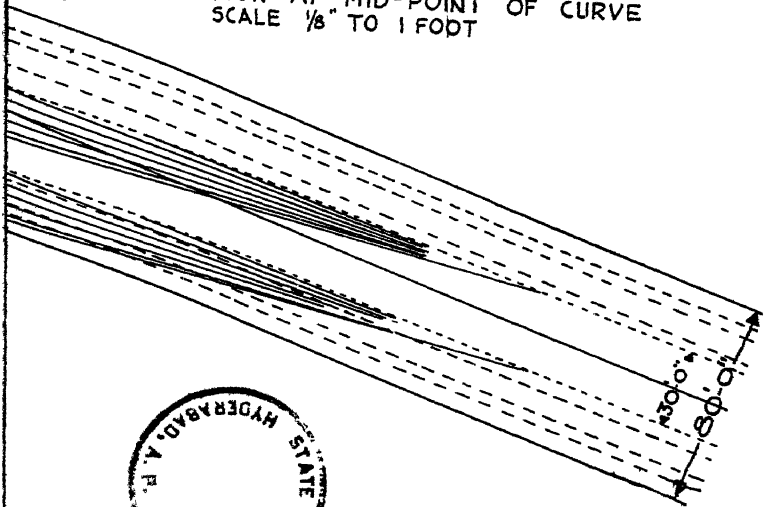
Another example of this method of intersecting the lemniscates is shown in Fig. 24, where the angle between the tangents is 30° and α is 10°, whilst the interior angle of intersection of the centre lines of road to be connected is 120°.

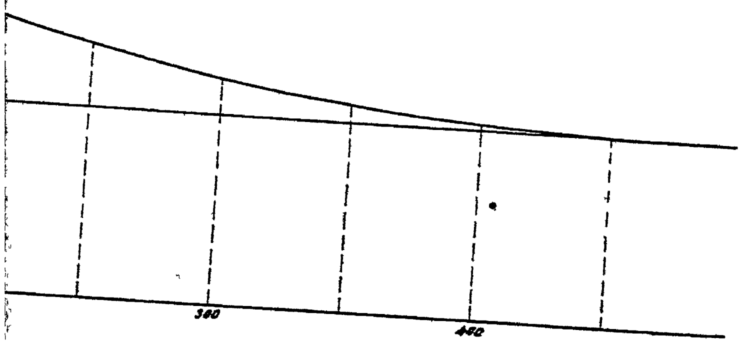
To use the lemniscate for transition to a main curve of, say 200-ft. radius we have from (2) $\sin 2\alpha = \frac{\rho}{3r}$.

* Sets of celluloid lemniscate transition curves in various sizes, designed by F. G. Royal-Dawson, M.Inst.C.E., may be obtained from Messrs. W. F. Stanley and Co., Ltd., 286 High Holborn, London.



ICAL CROSS SECTION AT MID-POINT OF CURVE
SCALE 1/8" TO 1 FOOT





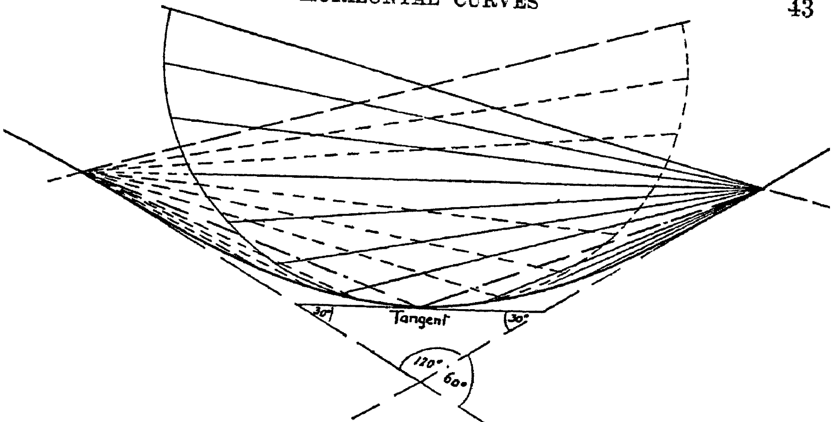


FIG. 24.—BERNOULLI'S LEMNISCATE FOR ROAD CURVES (OBTUSE ANGLE).

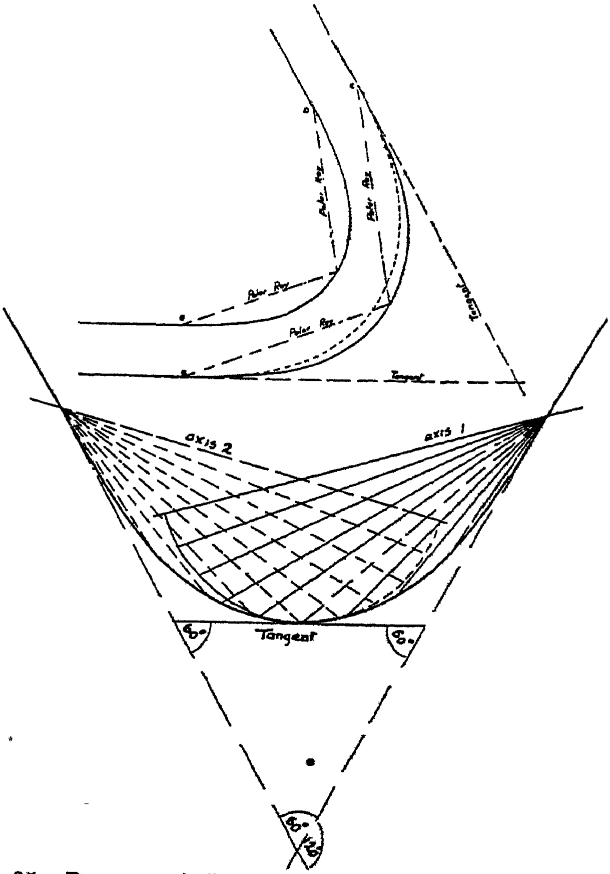


FIG. 25.—BERNOULLI'S LEMNISCATE FOR ROAD CURVES (ACUTE ANGLE), SHOWING NATURAL WIDENING.

If the length of transition is 50 ft., i.e. in order to apply the maximum superelevation, then $\rho = 50$ ft.,

and $$\sin 2\alpha = \frac{50}{600} = \frac{1}{12} \text{ or } 0{\cdot}0833$$
$$2\alpha = 4^\circ 40'$$
$$\alpha = 2^\circ 20'$$

which is the polar angle for $\rho = 50$ ft. and is the point of commencement *PC* of the main curve. Where the lemniscate is used more fully, it is a good plan to set out the kerb lines independently, as this gives a gradual widening to a maximum at the midpoint of the bend and at the point of greatest curvature.

This is shown clearly in Fig. 25, where two roads intersecting at an acute angle are connected by lemniscate curves.

An actual example of the setting out of this curve for a concrete road is given below:

The width of the road when widened was 45 ft., and the radius at the midpoint of the curve was 200 ft. The work was carried out in half-widths in order to keep the road open for traffic. The approximate centre line of the road at each bend was first determined, and the surface gradient defined with pegs. The inside kerb-line to a lemniscate curve was then set out with the theodolite, beginning at the tangent point on each side of the midpoint of the curve. The curve is shown in Fig. 26. Lemniscate curves were also set out for the outer kerb. The two kerbs will show a widening towards the middle point—in this case an amount of about 2 ft. on a 28-ft. carriage-way. The cross-fall was arranged as follows :—

Distance along the road on inner edge (ft.).	Rate of banking.		Corresponding radius of curvature (ft.).
	(Inch per foot.)	1 in ...	
0	$\frac{1}{8}$	1 in 96	nil
70	$\frac{1}{4}$	1 in 48	560
140	$\frac{1}{2}$	1 in 24	300
210	$\frac{3}{4}$	1 in 16	200
280	$\frac{1}{2}$	1 in 24	300
350	$\frac{1}{4}$	1 in 48	560
420	$\frac{1}{8}$	1 in 96	nil

It will be evident that with the cross-fall of 1 in 16 and a 200-ft. radius, a perfect balance between the forces of the weight of the vehicle, reaction from road, and centrifugal effect is obtained at a traffic speed of about 14 m.p.h.

At 300-ft. curvature, and cross-fall or banking of 1 in 24, a similar safe speed will apply.

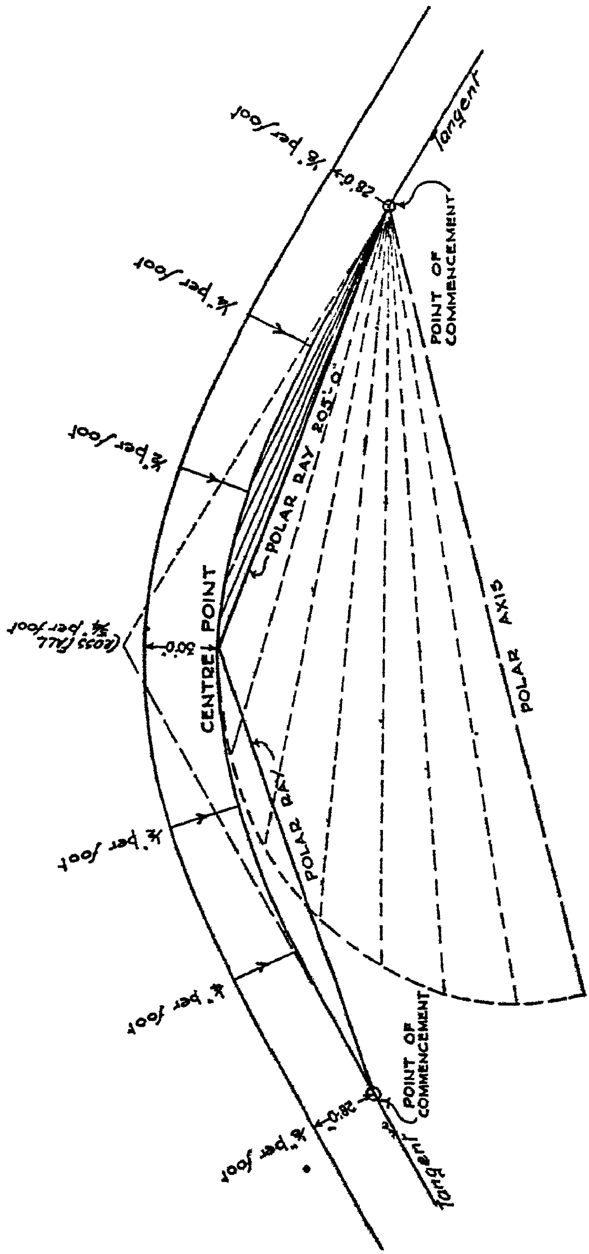


FIG. 26.—LEMNISCATE CURVE AT REDCLYFFE ROAD, BARTON.

Another useful application of this curve is for serpentine curves. The advantage in this case lies in the short straight length in the vicinity of point O, and the gradual deviation therefrom, although there is nothing to prevent the change of direction being made with a greater straight section between the curves to facilitate the change

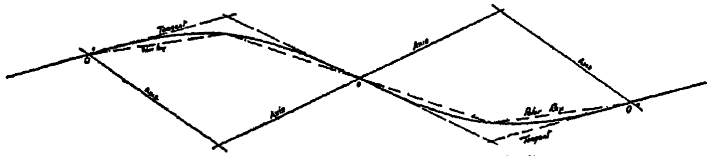


FIG. 27.—BERNOULLI'S LEMNISCATE FOR S CURVES.

from superelevated to crowned section. The example shown (Fig. 27), however, enables the banking to be performed with perfect safety.

Tables of offsets or polar co-ordinates may easily be prepared for main curves of varying radii.

The following table shows the values of sin 2α for values between O and 45° :—

VALUES OF SIN 2α AND $\sqrt{\text{SIN } 2\alpha}$ FOR $\rho = C\sqrt{\text{SIN } 2\alpha}$ AND $\rho = 3R \text{ SIN } 2\alpha$

α.	sin 2α.	$\sqrt{\sin 2\alpha}$.	α.	sin 2α.	$\sqrt{\sin 2\alpha}$.	α.	sin 2α.	$\sqrt{\sin 2\alpha}$.
44°	0·9993	0·9997	29°	0·8480	0·9208	14°	0·4694	0·6851
43°	0·9975	0·9988	28°	0·8290	0·9105	13°	0·4383	0·6621
42°	0·9945	0·9972	27°	0·8090	0·8995	12°	0·4067	0·6377
41°	0·9902	0·9952	26°	0·7880	0·8878	11°	0·3746	0·6120
40°	0·9848	0·9924	25°	0·7660	0·8752	10°	0·3420	0·5848
39°	0·9781	0·9891	24°	0·7431	0·8621	9°	0·3090	0·5559
38°	0·9702	0·9851	23°	0·7193	0·8481	8°	0·2756	0·5250
37°	0·9612	0·9804	22°	0·6946	0·8334	7°	0·2419	0·4919
36°	0·9510	0·9752	21°	0·6691	0·8180	6°	0·2079	0·4560
35°	0·9396	0·9694	20°	0·6427	0·8017	5°	0·1736	0·4166
34°	0·9271	0·9629	19°	0·6156	0·7846	4°	0·1391	0·3730
33°	0·9135	0·9559	18°	0·5877	0·7666	3°	0·1045	0·3233
32°	0·8987	0·9479	17°	0·5591	0·7477	2°	0·0697	0·2640
31°	0·8829	0·9397	16°	0·5299	0·7279	1°	0·0348	0·1866
30°	0·8660	0·9307	15°	0·5000	0·7071			

There is little doubt that the employment of superior curves for transition between the straight line and the circle will bring about an economy both in construction and maintenance of considerable value.

The question arises as to how far the transition curves should be adopted for the outside curves at bends, and here again the matter of economy comes in. If it is left as a simple curve it is certain that the tendency of motor traffic will be to travel towards the inner side of the road, especially about midway on the curve, and the outer

strip will be more or less useless. The adoption of easements or transition curves (e.g. the lemniscate) on the outside similar to those on the inside is therefore an advantage in many cases, although on existing roads the cost of alteration may perhaps be avoided.

Need of Increased Width on Curves.

It is highly important, however, to have a definite increased width on the quick bends where inner and outer transition is effected.

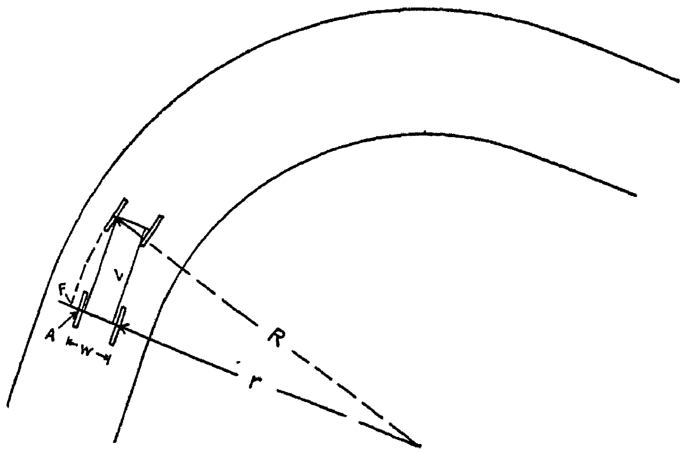


FIG. 28.—DIAGRAM SHOWING THE EXTRA WIDTH REQUIRED AT BENDS.

The extra width required by motor vehicles may be determined in the following manner —

In Fig. 28 let R = the radius to the outer front wheel—i.e. the radius of the curve—and r the radius of the curve traversed by the inner rear wheel. Let l = wheel-base and w the width between rear wheels. If the arc of radius R is made to cut the line passing through the rear axle in point F, then FA represents the extra width required in turning.

Then $\qquad R - (r + w) = FA.$

But $\qquad (r + w) = \sqrt{R^2 - l^2}.$

$$FA = R - \sqrt{R^2 - l^2}.$$

This value should be doubled in ordinary cases to allow of vehicles passing in each direction. The following table represents the amount of extra width for different radius turns, taking motor lorries of 16-ft. wheel-base. In addition to the calculated width it is advisable to increase this to allow a greater margin for clearance in negotiating such bends.

Radius at centre line (ft.).	Extra width for one vehicle (ft.).	Extra width for two vehicles (ft.).	Suggested extra width to allow for turning with two lines of traffic (ft.).
25	4·7	9·4	12
50	2·5	5·0	8
75	1·65	3·3	6
100	1·3	2·6	5
125	1·0	2·0	4
150	·8	1·6	3
200	·5	1·0	3

Taking l = the wheel-base = 16 ft.

The suggested additional widths in the fourth column of the table will be found sufficient for a wheel-base of 20 ft. There are many vehicles to-day of the six-wheel type which have wheel-bases of more than 20 ft.

Curves for Right-angled Intersections.

Another interesting example of the application of the lemniscate curve for a right-angled turn or intersection is shown in Fig. 21. The portion of the transition curve between the point of origin and the mid-point is similar on either side, the greatest curvature being at the midpoint. This enables vehicles making a left turn to follow closely the path of the kerb, with a minimum of interference to other traffic.

In the case of the ordinary circular curve, it is necessary for a vehicle to pull out into the middle of the road in order to clear the kerb with the rear wheel.

If, however, transition curves are not adopted, it is advantageous to introduce circular curves of as large a radius as possible. If one or both roads are narrow, a wide mouth or entrance from one to the other is a precaution in the interests of public safety. In country areas this improvement can usually be effected without much difficulty, but in towns existing buildings frequently complicate matters by obstructing the view and preventing an improvement on account of the great expense involved. In such cases for any degree of safety low speeds are a necessity.

Road Mirrors for Blind Turnings.

This device is usually placed at an angle, so that traffic going along either road and approaching the corner can see the traffic on the other. The idea of the mirror is certainly sound, as it gives warning from one road to the other. Its usefulness depends largely on force of habit;

a stranger, for instance, would probably miss seeing the mirror or, if unacquainted with it, he might at first glance think he was about to run into a vehicle in the vicinity of the reflector, especially during darkness. The mirror may be oblong in shape, and should be sufficiently high to be useful to drivers at different elevations. Fig. 29 shows an arrangement for a double mirror to assist traffic passing out of a concealed turning into a main road.

These mirrors are now largely superseded by the automatic traffic

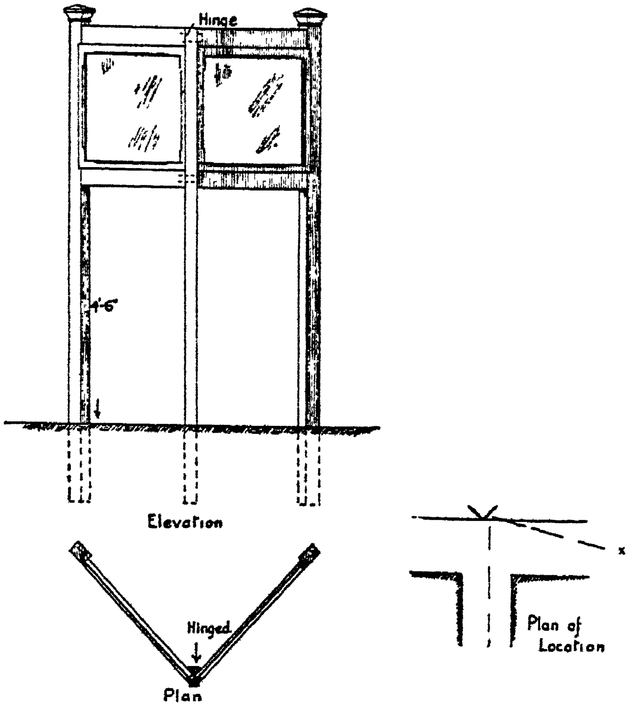


FIG. 29.—DOUBLE ROAD MIRROR FOR CONCEALED TURNING.

signal, which gives absolute control of the intersection. These signals are dealt with in a later chapter.

Note.—See Clark's *Plane and Geodetic Surveying* (Vol. I), Constable & Co., for further information *re* transition curves and general setting out.

RANGE OF VISION

The question of curvature and of vertical curves is of the utmost importance in determining a safe range of vision and for giving an ability to see ahead when travelling at speed.

When the sight distance is insufficient, overtaking with safety is

not possible on a two-lane highway; the minimum "non-passing" distance depends on time of reaction upon sighting a stationary object, the time needed to bring a vehicle to a stop according to design speed

A formula used at one time by the Indian P W.D. was as follows :—

$$\text{Limit of view (in feet)} = \frac{V^2}{2}$$

$$(V = \text{speed in m p.h.})$$

In determining braking distance, d, on a level road, friction between tyres and road surface must be considered; this force is not uniform, but a moderate uniform or average value may be assumed in the following formula :—

$$d = \frac{V^2}{30f}$$

$$f = 0{\cdot}50 \text{ at 30 m.p.h., and } 0{\cdot}40 \text{ at 70 m.p.h.}$$

The value of d plus the perception and reaction and time of braking gives the minimum non-passing sight distance; these are given for various speeds in the table below.

Assumed design speed		Reaction distance (ft.).	Safe coefficient of friction (f).	Braking distance on level (ft.).	Recommended (A.A.S.H.O.) *, minimum sight distance (ft.).
(m.p.h.).	(ft per sec.).				
30	44	132	0 50	60	200
40	59	162	0·47	113	275
50	73	183	0·45	185	350
60	88	198	0·42	286	475
70	103	206	0·40	408	600

If the road is up- or down-hill the braking distance is respectively less or greater and the formula is modified as follows :—

$$d = \frac{V^2}{30\,(f \pm \text{gradient }\%)}$$

For a 6% up gradient this will decrease the stopping distance from 10 to 50 ft., and increase it 10 and 70 ft. for 30 and 70 m.p.h. respectively on the down-grade.

It is desirable to have many sections on a highway where safe passing can be made; these sections should be approximately 1 mile in length, although much depends on the density of traffic using the road.

* American Association of State Highway Officials.

Spacing of Moving Vehicles.

In general, it may be said that the faster the speed the greater is the distance observed between vehicles in the same lane, and therefore even at slow speeds the amount of traffic passing per hour is almost as great as at the higher speeds.

From observations made and from assumptions the spacing of vehicles may be determined from the expression $S = V + 20$, where S is in feet and V in miles per hour.

Thus at 10 m.p.h. S is 30 ft., at 30 m.p.h. it is 50 ft., and at 60 m.p.h. it is 80 ft.

In the matter of overtaking, the safe passing distance, d', is affected by the speed of the vehicle overtaken, and the less the difference in the speed of the two vehicles the greater will be the distance, d'.

When there is an opposing vehicle, the safe distance to allow overtaking will be reduced; the speed that matters is the sum of the speeds of the opposing vehicles; this is sometimes known as the "closing speed"; because of this, it is usually advisable for a driver about to overtake, to refrain and remain behind the preceding vehicle until the lane for overtaking is clear.

Sight Distance at Intersections.

Where possible, approaches to intersections and to circles should be arranged to give a clear view of the junction and of the intersecting road, to minimize the risk of accidents. The Road Improvement Act of 1925 and the Restriction of Ribbon Development Act of 1935 give powers to prevent obstruction and to obtain visibility at corners. The rule that traffic proceeding from the right has preference should be enforced to ensure safety and to avoid confusion.

The safe stopping distance (d) is an important factor which depends on the design speed; values for d may be obtained from the following formula; this allows for personal reaction time and a coefficient of friction of 0·4:—

$$d = 2{\cdot}93V + 0{\cdot}083V^2,$$

where V is in m.p.h.

Traffic-warning signs (properly sited) will usually indicate the approach of an intersection or junction, and in built-up areas speeds (with 30 m.p.h. limit) will be of the order of 20 m.p.h.; the minimum sight triangle recommended in Ministry of Transport Memorandum 575 is "a line joining (a) a point about 50 ft. along the near side kerb line to (b) a point about 55 ft. along the centre line of the intersection road"; this may be modified by lengthening one of the sight lines if required.

If speeds of 30 m.p.h. are common, the lines (a) and (b) should be increased to 110 ft. and 55 ft., respectively.

On the open road the minimum range of visibility of 1,000 ft. between approaching vehicles should apply for single carriage-ways; otherwise white line markings are essential

All minor obstructions, such as fences, earth banks, call-boxes, etc., should be removed.

The Author observed two cases in America where "Halt" signs were used at all four roads approaching an intersection, one in a busy city and the other in open country. The method was entirely

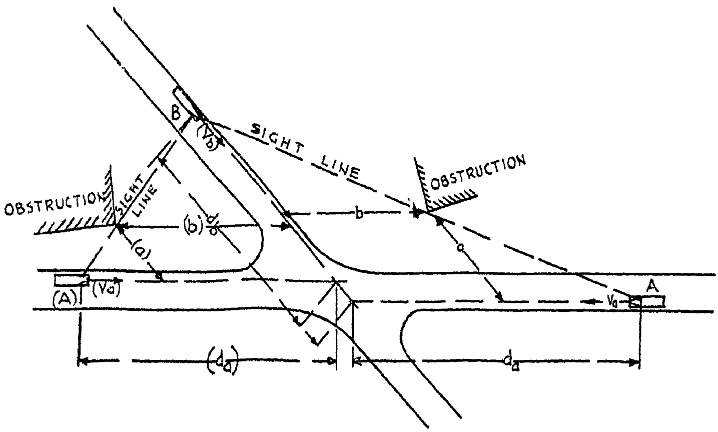


FIG. 30.—DIAGRAM SHOWING SIGHT DISTANCE (ACUTE ANGLE AT INTERSECTION).

successful where traffic was light, but at busy times in the city area confusion occurred.

In the case of oblique junctions which cannot easily be modified, the acute angle requires a very sharp angle of observation (by drivers) towards the opposing road (see Fig. 30).

It would be useful to indicate on a minor road, where "Halt" signs are not used, the safe speed at which the approach to the major or "preference" road should be made. This could be amplified by means of signs for stepping down speeds in villages as the centre is approached, commencing at 25 m.p.h., decreasing to 20, with 15 at the busy centre or cross road, and increasing in the same ratio from 15 to 20 and 25 m.p.h. into the unrestricted area of open country.

VERTICAL CURVES

WHEREVER there is an abrupt change of gradient it is desirable to introduce a vertical curve for smooth running and to ensure a sufficient range of visibility for safety. These may be (*a*) convex or summit curves or (*b*) concave or valley curves. The question of visibility affects the summit curves rather than the valley curves

Summit Curves.

The length of a summit curve (Fig. 31), depends on the difference in the rate of the intersecting gradients; up-gradients are expressed

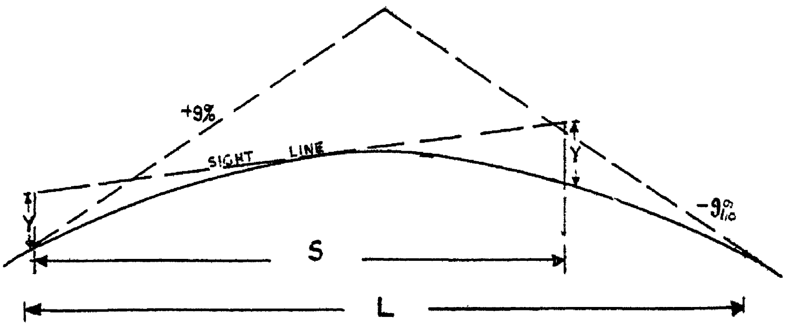


FIG 31 —SUMMIT CURVE.

as positive and down-gradients as negative, e.g. an up-grade of $+4\%$ and a down-grade of 5%) would give an intersecting gradient of 9%.

Clearly the rate of change of gradient is a factor which affects the smooth passage of a vehicle over a curve

Valley Curves.

With valley curves, centrifugal force acts with gravity, thus causing greater pressure on the road surface; consequently small changes of gradient, or even defects in the road surface, set up harmonic vibration in the vehicle and impulsive driving at the rear axle, thus causing corrugation and road wear.

In the case of summit curves, centrifugal force acts against gravity; nevertheless a smooth change of gradient is essential.

Suitability of Parabolic Curve.

The parabola is admirably suited for vertical curves; the offsets vary as the square of the distance, hence the curve is simpler to apply than the circular curve.

For the small values for the intersecting gradient in practice the parabolic corresponds closely to the circular curve.

In Fig. 32 the middle point C is half-way between A and B. If

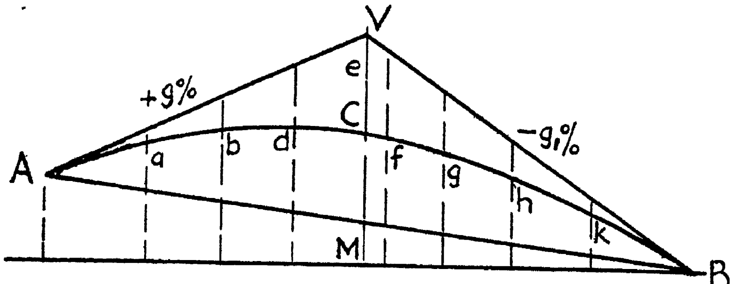


FIG. 32.—PARABOLIC VERTICAL CURVE (HICKERSON).

VA = VB, AC = BC = l and $e = VC$, i.e. the versine, $2l \doteq$ length of curve,

then the height of A relative to $V = + g \times \frac{l}{100}$

" " B " " $= g_1 \times \frac{l}{100}$

" " M " " $= \frac{1}{2}(g - g_1) \times \frac{l}{100}$

" " C " " $= \frac{1}{4}(g - g_1) \times \frac{l}{100} = e$

$$e = \tfrac{1}{8}(g - g_1) \times \frac{2l}{100}$$

The equation for a parabola is $Y = Kx^2$; thus Y varies as the square of the distance X.

Length of Vision.

From the properties of the parabola it can be shown that the required length of vision is less than the length of the curve L (Fig. 31).

$$L = \frac{S^2(g - g_1)}{8Y \times 100}$$

where S = required length of vision and Y = height of eye above carriage-way level (say 4 ft.).

For small-grade angles the visibility is ensured irrespective of the vertical curve employed.

The above formula should be used where the length of vision S will be greater than the length of the curve.

Values of S depend to some extent on the speed limit of the road; a distance of 300 ft. may be regarded as suitable for a speed of 35 m.p.h. The importance of vision is almost as great for one-way

roads as for two-way in case of a breakdown of a vehicle causing an obstruction.

In the case of two-way roads white centre lines, staggered near the summit, make for greater road safety where vision is limited.

The Lemniscate for Valley Curves.

The lemniscate curve lends itself to small changes of gradient, more particularly for valley curves where there are two varying

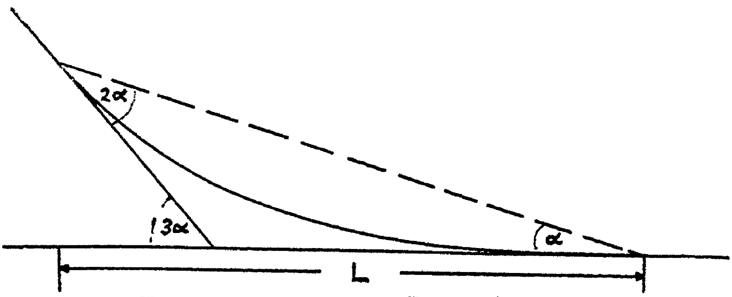


FIG. 33.—LEMNISCATE FOR BRIDGE APPROACH.

down-gradients or a down-gradient meeting a level section or a rail or road intersection.

Let us suppose that an approach down-gradient of 5% (1 in 20) meets a level section, as shown in Fig. 33. Select a suitable length, l, for transition—say 100 ft.; then $\sigma = 100$ and α is determined.

$$\text{Tan } 3\alpha = \frac{1}{20} = 0\ 05$$

$$3\alpha = 3^\circ \text{ approx. } \therefore \alpha = 1^\circ$$

and $$C = \frac{\rho}{\sqrt{\sin 2\alpha}} = \frac{100}{0{\cdot}1872} = 534.$$

If $\alpha = 1^\circ$, then from Tan α the height of the upper tangent point is 1 ft. 9 in. above the lower tangent point, i.e. at the level section.

Other values and heights for ρ between zero and 100 ft. may readily be calculated.

To set out the curve the theodolite is set up at the lower P.T., the height of the instrument being carefully noted; using the levelling staff and either the tape or tacheometry, the exact height of the road may be fixed, by pegs, by reading the vertical angles, α, on to the staff at the height of the instrument.

Vertical Curves at Under-crossings.

The sight distance at an underbridge crossing depends on the gradients and length of the vertical curve; with a minimum clear-

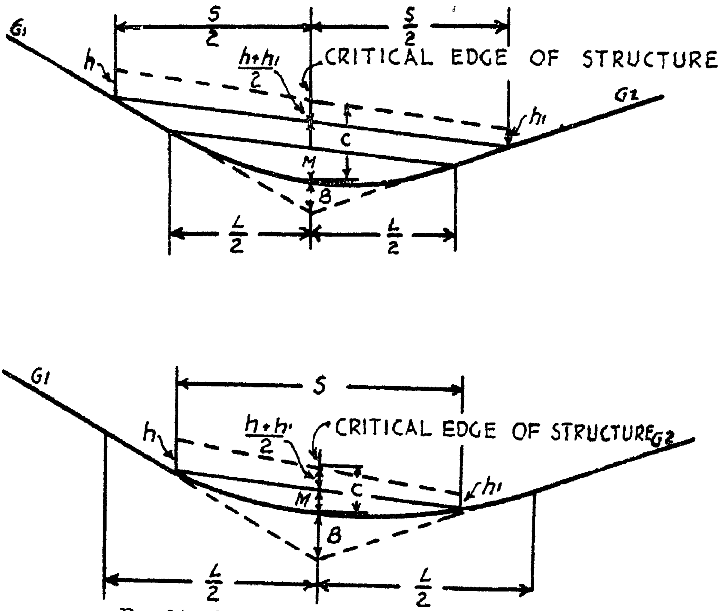


FIG. 34.—SIGHT DISTANCE FOR UNDERCROSSINGS.

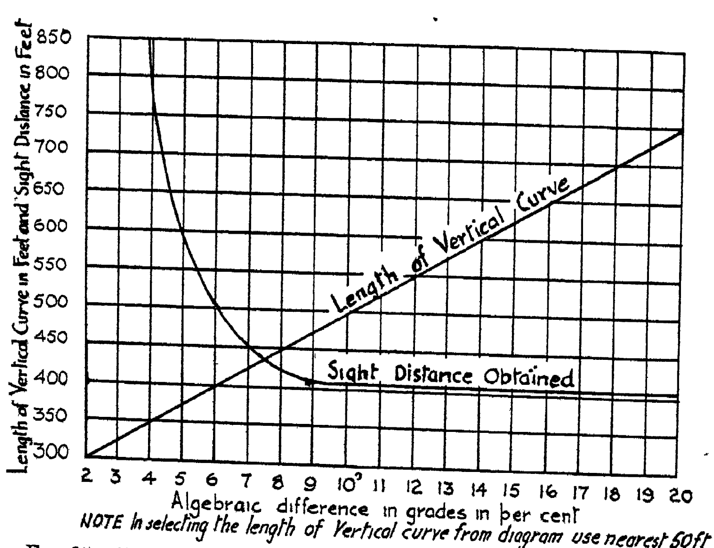


FIG. 35.—DIAGRAM SHOWING LENGTH OF VERTICAL CURVE AND SIGHT DISTANCE FOR DIFFERENCES IN GRADE % (ILLINOIS PRACTICE).

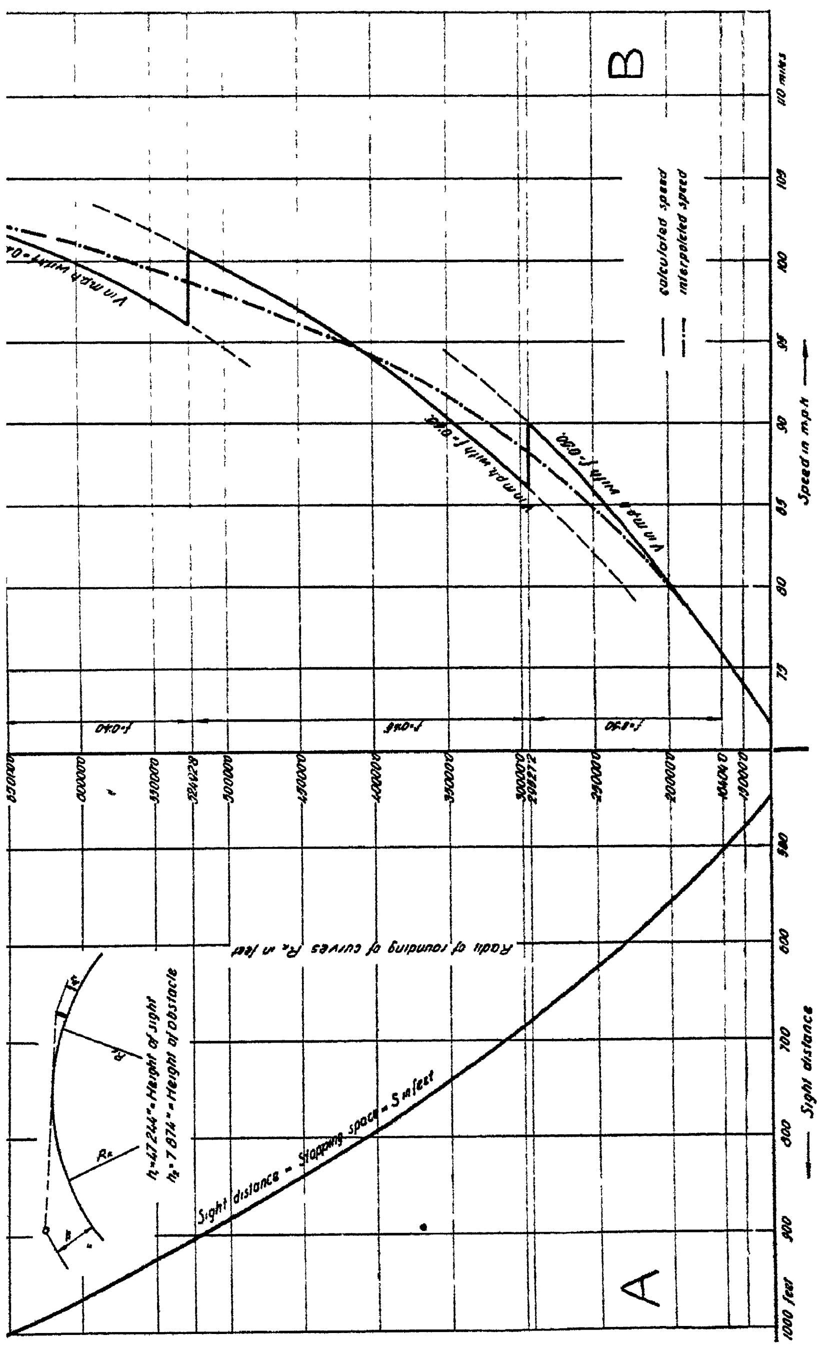


FIG. 36.—SIGHT DISTANCE (A) AND VERTICAL CURVATURE (B) ON GERMAN AUTOBAHN.

ance of 16 ft. (14 ft. in U.S.A.) the sight distance may be determined as shown in Fig. 34; the length of curve

$$L = 25 - \frac{82}{A}. \qquad A = g_1 - (-g_2).$$

A longer sight distance may be obtained by using a longer vertical curve and adjusting the gradients, always ensuring the minimum bridge headroom.

A useful graph is reproduced in Fig. 35 showing the sight distance relative to the length of vertical curves and the algebraic difference in gradients per cent; the data represents practice in the State of Illinois, U.S.A.

German Standards.

The vertical curve standards in the German autobahn are shown in tables in Chapter VII, and the sight distance relative to radius of curvature is depicted graphically in Fig. 36.

The 1942 specification recommends that the final line of the road should be decided by means of models, or space or perspective drawings, in order to obviate the errors in appearance caused by the incorrect design of the vertical curves relative to the horizontal curves and the straight lengths.

CHAPTER VI

SUPERELEVATION ON HIGHWAY CURVES AND JUNCTIONS

SUPERELEVATION on curves has hitherto been confined to railway design In the days when the roads were dedicated to horse traffic the need for banking up the outer portion of a curve was never considered, and the cambered section was the rule rather than the exception.

It was in 1921 that the Ministry of Transport issued instructions to divisional engineers to the effect that superelevation should be introduced, where desirable, in all improvement schemes; and it took more than twenty years for it to become accepted practice.

The disadvantages of the cambered section of the road surface at bends may be stated under the following headings —

(a) *Excessive Wear.*

There is no part of a road surface which fails so quickly as that of bends. This is due to the action of centrifugal force, which produces unequal pressure on the wheels, thus causing vibrations and consequent damage to the wearing surfaces, usually in the form of waves or potholes.

(b) *Danger of Skidding and Colliding.*

The possibilities of accidents occurring at a sharp bend are fairly apparent to most users and observers of road surfaces. The natural tendency of all modern motor traffic, whatever its direction, is to cut in on the inside of the turn in order to obtain assistance from the banking effect of the inner camber. This is really what occurs in practice, and under these conditions the outer half of the road is subjected to very little wear. The result is that there is a serious danger of collision occurring on cambered sections; any sudden change of direction or the application of the brakes will cause the vehicle to skid, owing to the uneven pressure on the rear wheels and the uneven wavy road surface. Moreover, tyres are more easily torn or burst from the rim when rounding bends. Many accidents have been recorded in these circumstances.

(c) *Danger to Vehicles Travelling on the Outside Bend.*

Inevitably it happens that a vehicle is compelled to travel on the outside bend owing to the inner slope being in use by traffic going in

the opposite direction. The effect of the outer slope combined with the turning of the vehicle itself may result in a strong overturning or skidding tendency.

(d) *Effective Width Reduced.*

On the sharper curves the outer portion of the road tends to be little used. Many drivers are quite unaware of the amount of extra

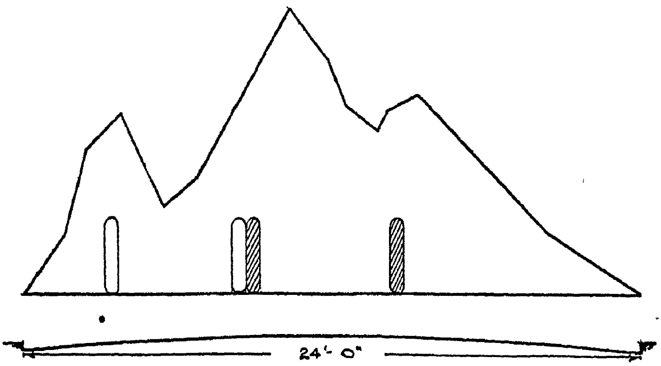


FIG. 37(*a*).—DISTRIBUTION OF WHEEL TRAFFIC ON LEFT-HAND CURVE CAMBERED SECTION.

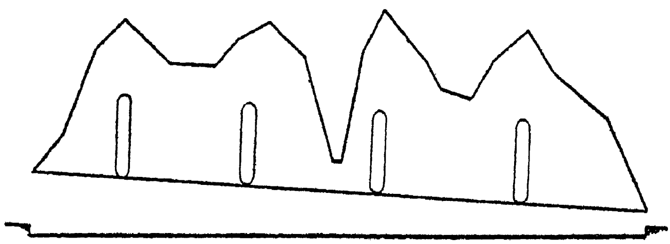


FIG. 37(*b*).—DISTRIBUTION OF WHEELED TRAFFIC, SUPERELEVATED SECTION.

width required in steering round a curve, and this causes concentration on the inner face.

This point is fully illustrated in the diagrams (Figs. 37 (*a*) and (*b*), 38 and 39), showing the distribution of wheel traffic and consequent wear on (*a*) a curve of cambered section, (*b*) a superelevated curve without camber.

It is true that the principle of banking has long been in use in this country for cycle and motor-racing tracks, and it is all the more extraordinary that there has been no general policy to embody it in road construction—at any rate, on first-class roads—until recently.

It will be seen that the disadvantages are eliminated by the adoption of superelevation, the chief advantages of which are :—

(a) It reduces the strain on road foundations and the wear on road surfaces.
(b) It reduces the strain on the steering parts of the vehicle and the wear on tyres, which have less tendency to burst off under the action of centrifugal force.

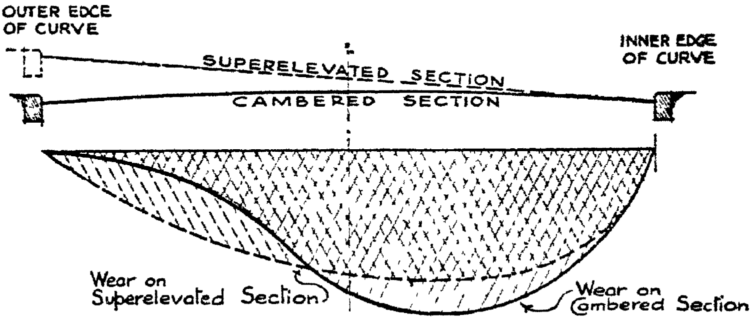


FIG. 38.—DISTRIBUTION OF WEAR, CAMBERED AND SUPERELEVATED SECTION.

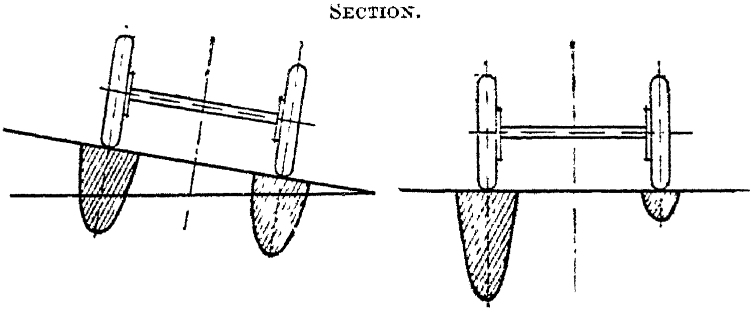


FIG. 39.—DISTRIBUTION OF PRESSURE ON BANKED AND UNBANKED CURVES.

(c) It assists drivers in safely negotiating curves at night or in foggy weather, when vision is difficult.
(d) White lines or reflector studs may be laid down and adhered to with safety. (In the absence of white lines or studs a superelevated curve is reasonably safe.)
(e) The range of vision is increased by the motorist using the outer side in taking a right-hand curve.
(f) The surface is self-cleansing, and the drainage economically dealt with on the inside of the curve by gullies, etc.
(g) It reduces vibration and movement of the load by keeping the pressure due to the weight as nearly normal as possible to the road surface. Fig. 39 illustrates the distribution of weight on a banked and on an unbanked curve.

The analysis of superelevation consists in determining the amount by which the outer edge of the road at a curve must be raised above the inner edge in order to counteract, through the wheels at the road surface, the centrifugal force acting on the vehicle according to its speed and the radius of curvature. The effect of this tilting or cross-fall is to move the centre of gravity inwards sufficiently to balance the outward effect of the centrifugal force.

In Fig. 40 if W = the weight in lb. of the vehicle and R the radius of the curve (in ft.), the centrifugal force $CF = \frac{Wv^2}{gR}$, where v = the velocity in ft. per sec. and $g = 32{\cdot}16$ ft per sec. per sec. The three forces W, R, and CF intersect in one point, being in equilibrium, and

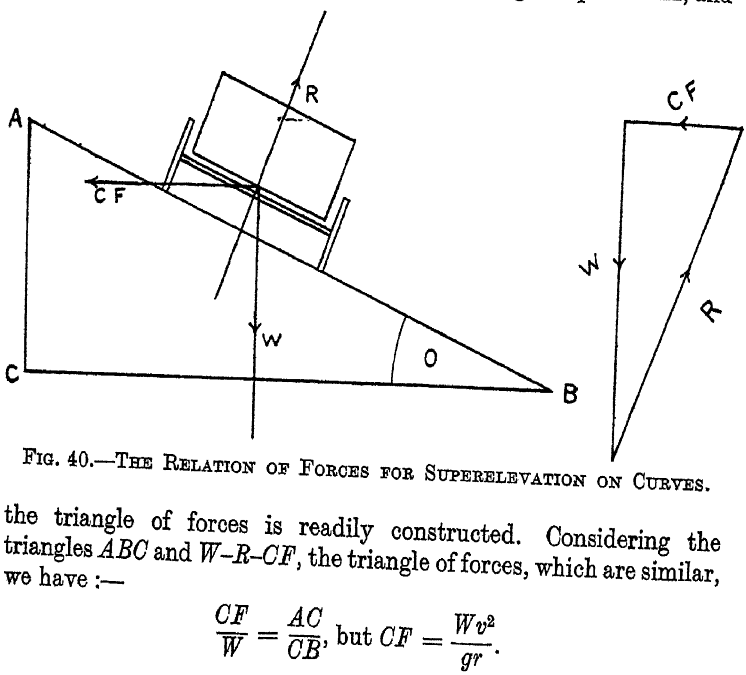


FIG. 40.—THE RELATION OF FORCES FOR SUPERELEVATION ON CURVES.

the triangle of forces is readily constructed. Considering the triangles ABC and W–R–CF, the triangle of forces, which are similar, we have :—

$$\frac{CF}{W} = \frac{AC}{CB}, \text{ but } CF = \frac{Wv^2}{gr}.$$

$$\therefore \quad AC = \frac{Wv^2}{gr} \times \frac{CB}{W} = \frac{CB \times v^2}{gr}.$$

By substituting unity for CB, 32·16 ft. per sec. per sec. for g, and V m.p.h. for v, the superelevation per ft. width of road is obtained, viz. :—

$$AC = \frac{V^2}{15r} \text{ (nearly)} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Assuming a speed of 20 m.p.h. on a curve of radius 100 ft., this would give a value for superelevation of 0·26 ft. per ft. width, or roughly 1 in 4. It is obvious that this value is far in excess of a

safe cross-fall to accommodate all kinds of traffic and tyres under varying speeds. With a larger radius greater speeds are usual and the calculated cross-fall may be about the same, viz. 1 in 4 or 5. It is the engineer's duty, therefore, to reduce this calculated value for banking to a figure which will produce conditions of safety for both slow and fast traffic Generally the rate of superelevation should not exceed 1 in 10 and, indeed, it has been argued that this is excessive for double-deck buses or for horse traffic. This cross-fall—i e. 1 in 10—is sufficient to provide a reaction which will balance substantially the centrifugal force of vehicles at 20–30 m.p.h. on curves of radius of 100–200 ft.; the remainder must come from the friction of the tyres themselves at the road surface The least radius of curvature

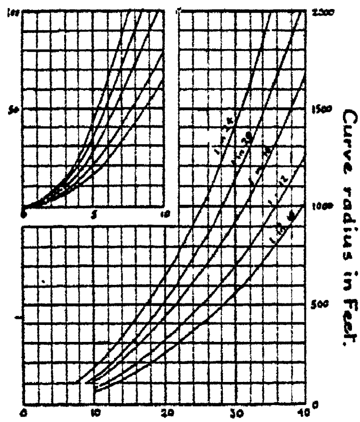


FIG. 41.—GRAPH SHOWING THE RELATION OF SPEED AND CURVATURE FOR COMPLETE SUPERELEVATION.

for a speed allowance of 25 m.p.h. at 1 in 10 to produce no side thrust on the road is about 415 ft., and for a speed allowance of 20 m.p.h. is 267 ft.

It should be mentioned here that there is still an element of prejudice in existence against the adoption of superelevation in this country. This arises from the belief that banking will encourage racing and an increase of speed generally, which is largely an argument built upon imagination, and probably arising from the recollection of well-banked racing tracks. Having regard, however, to the fact that the permissible allowance for superelevation can only partially accommodate side thrust, there is no cause for alarm in such proposals.

The following table and also the graph in Fig. 41 indicate the least radius of curvature which would give complete protection to traffic,

or full banking effect with no side thrust on the road surface at different speeds :—

VALUES OF RADIUS OF CURVATURE FOR COMPLETE BANKING EFFECT

Speed value (m.p.h.).	1 in 10 or 1·2 in. to 1 ft (ft.).	1 in 12 or 1 in. to 1 ft. (ft.).	1 in 16 or ¾ in to 1 ft. (ft.).	1 in 24 or ½ in to 1 ft (ft.).
15	150	180	240	360
20	267	320	427	640
25	415	500	667	1,000
30	600	720	960	1,440

Conditions where Level or Insufficiently Superelevated.

Where road curves are not superelevated the limiting conditions of equilibrium of a vehicle passing round the curve will be when the inner wheel is taking no load, and the reaction acting from the outer wheel passes through the centre of gravity as in Fig. 42. The centrifugal force will be the same as the horizontal frictional force

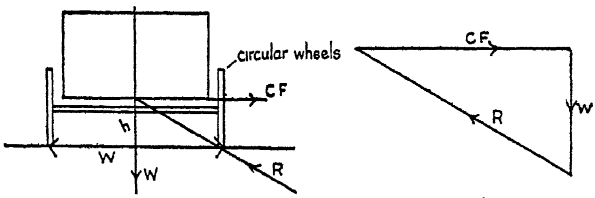


FIG. 42.—DIAGRAM SHOWING THE RELATION OF FORCES ON VEHICLE ON CURVES NOT SUPERELEVATED.

acting at the wheel tyre; and the overturning moment will just be balanced by the righting moment.

Centrifugal force $= \dfrac{Wv^2}{gr}$.

Let h = height of centre of gravity and w = gauge of wheels.

Then $$\frac{Wv^2}{gr} \times h = W \times \frac{w}{2}.$$

But $$\frac{Wv^2}{gr} \times \frac{1}{W} = \frac{v^2}{gr} = \mu, \text{ coefficient of friction.}$$

Now, if we take μ as being equal to 0·25, the centrifugal force must be equal to one quarter the normal pressure of the vehicle—in this case $= W$. It is clear, therefore, that in order to overturn, the height h of the centre of gravity must exceed twice the gauge of the wheels, that is to say, $CF \times 2w > W \times \frac{w}{2}$; but the height of the

entre of gravity is usually much less than w, and it is therefore lmost impossible for a motor bus to overturn when rounding a bend, ecause skidding would occur in the first place to prevent it, e g. —

$$\text{If } h = w, \text{ then } CF \times w = W \times \frac{w}{2}.$$

$$\therefore \frac{CF}{W} = 0{\cdot}5 = \mu, \text{ the coefficient of friction.}$$

But even under rough conditions of surface, and with the best on-skid tyres, it cannot be conceived that the value of μ would ever

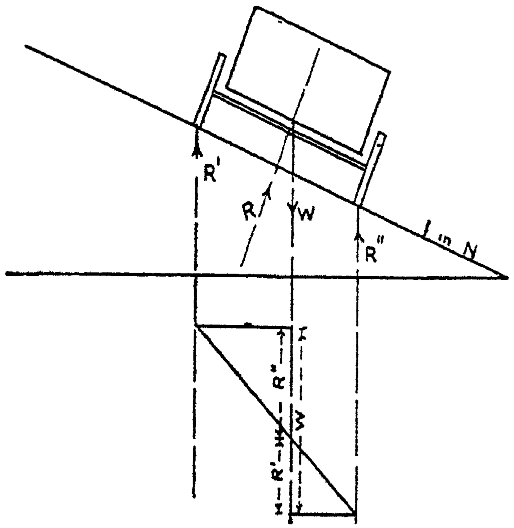


FIG. 43.—RELATION OF FORCES ON STANDING VEHICLE ON SUPER-ELEVATED CURVE

pproach 0·5, and skidding would occur before overturning could ake place.

In the case of a road where the surface is insufficiently banked to revent side thrust or friction at the point of contact with the wheels, he various forces may be determined graphically in the manner hown in Fig. 40. Knowing the speed and weight of the vehicle nd also the radius of curvature of the road, the value of the centri-ugal force is readily calculated. Then, by the principle of the riangle of forces, the three forces acting on the vehicle must now pass through the one point, viz. the centre of gravity for conditions f equilibrium; the magnitude and direction of the total reaction rom the road are then found in the usual way.

The coefficient of friction at each wheel contact is approximately he same, although the wheel-loads are different, and the value and irection of the reactions at the wheels may be obtained by first resolving the total reaction R, graphically, as shown in Fig. 43.

The values of R' and R'' are easily resolved into the normal and frictional forces by parallelogram of forces.

The problem may be further considered graphically (Fig 44) as follows —

Let $$1 \text{ in } N = \text{rate of banking.}$$

Then $$\tan \theta = \frac{1}{N}$$

and $$\cos (\theta + \phi) = \frac{F}{R} = \mu,$$

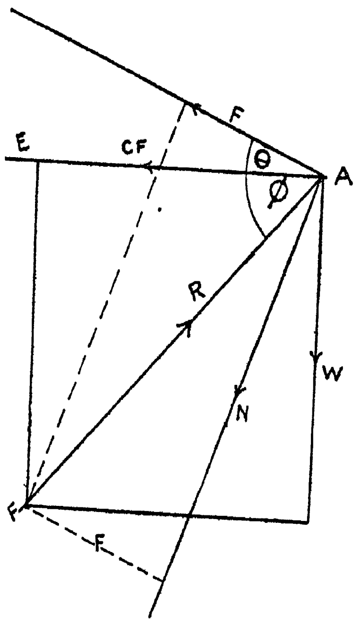


FIG. 44.—DIAGRAM SHOWING THE RELATION BETWEEN FRICTIONAL FORCE, SUPERELEVATION, CURVATURE AND SPEED.

the resultant R of the forces W and centrifugal force CF found by parallelogram of forces, and afterwards resolved into a normal force N and F.

Then $$\frac{CF}{W} = \frac{v^2}{gr} = \cot \phi.$$

Taking the limiting value of μ at 0·25 for average conditions we can readily determine the safe speeds round bends according to the radius of curvature and slope of banking.

An example is given here to indicate the application of this formula :—

Let $$r = 300 \text{ ft. radius and rate of banking 1 in 12.}$$

Then $\tan\theta = \frac{1}{12} = 0{\cdot}0833$

and $\theta = 4^\circ\ 45'.$

Now $\cos(\theta + \phi) = \frac{F}{R} = 0{\cdot}25.$

$\therefore \theta + \phi = 75^\circ\ 29'$

and $\phi = 75^\circ\ 29' - 4^\circ\ 45' = 70^\circ\ 44'.$

In triangle AEF,

$$\frac{W}{CF} = \tan\phi = \frac{gr}{v^2}.$$

$$\therefore \quad v = \sqrt{\frac{gr}{\tan\phi}} = \sqrt{\frac{32 \times 300}{2{\cdot}861}} = \sqrt{3355} = 58 \text{ ft. per sec.}$$

$$= 40 \text{ miles per hour approx.}$$

The safe speeds for various slopes of banking and various curvature are shown in the following table and the graph in Fig. 45 :—

TABLE SHOWING SAFE SPEEDS FOR VARIOUS CURVATURES AND SLOPES OF BANKING FOR COEFFICIENCY OF FRICTION $\mu = 0{\cdot}25$.

Rate of banking.	Radius of curvature in feet.							
	25	50	75	100	125	150	175	200
	V. Miles per hour.							
1 in 5	13·6	19	23·2	36·9	30	32·7	38·2	42·6
1 in 8	12·2	17	21·1	24·2	27·3	29·6	34	38·2
1 in 10	11·8	16·7	20·4	23·6	26·4	28·8	33·4	37·2
1 in 12	11·6	16·3	19·8	22·8	25·6	27·9	32·4	36·1
1 in 16	10·9	15·7	19	21·8	24·5	26·9	31	34·7
1 in 24	10·5	15	18·4	21·1	23·8	25·9	30	33·7

The ratio of centrifugal force to weight of vehicle at different curvature and speeds on level cross-sections—i.e. without superelevation—is of interest, as this represents the coefficient of friction; this is shown in the graph, Fig. 46.

As a matter of interest, the official graph issued in Scotland at an early stage of progress in superelevation is reproduced in Fig. 47.

The Methods of Effecting Superelevation.

Generally the section of the road to be dealt with is cambered, and it is necessary for this slope to be changed gradually to a continuous slope from outer to inner edge of the curve. The change may be accomplished by revolving the surface either (*a*) about the inner

edge of the pavement as an axis or (*b*) about the axis of its centre line, as shown in Fig. 48. In flat districts it is advisable to elevate on the inner line to prevent drainage trouble or flooding.

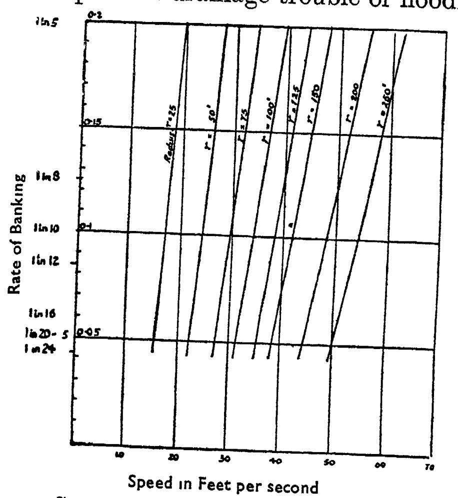


FIG. 45.—GRAPH SHOWING RELATION BETWEEN CURVATURE, RATE OF BANKING AND SAFE SPEED.

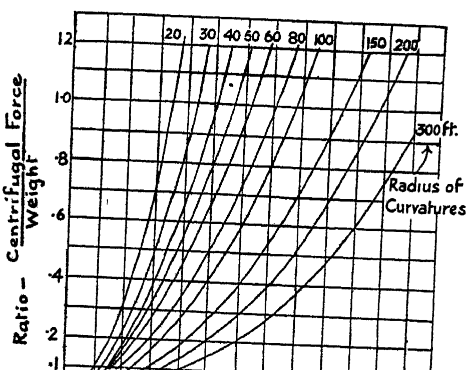


FIG. 46.—GRAPH SHOWING CENTRIFUGAL FORCE/WEIGHT RATIO TO SPEED FOR VARIOUS CURVATURES.

A superelevation rate of 1 in 24 would mean in practice the extension of the inner slope of a well cambered road.

Setting out—Rate of Change.

The question naturally arises as to the most suitable point to commence making the change from camber to superelevation; the

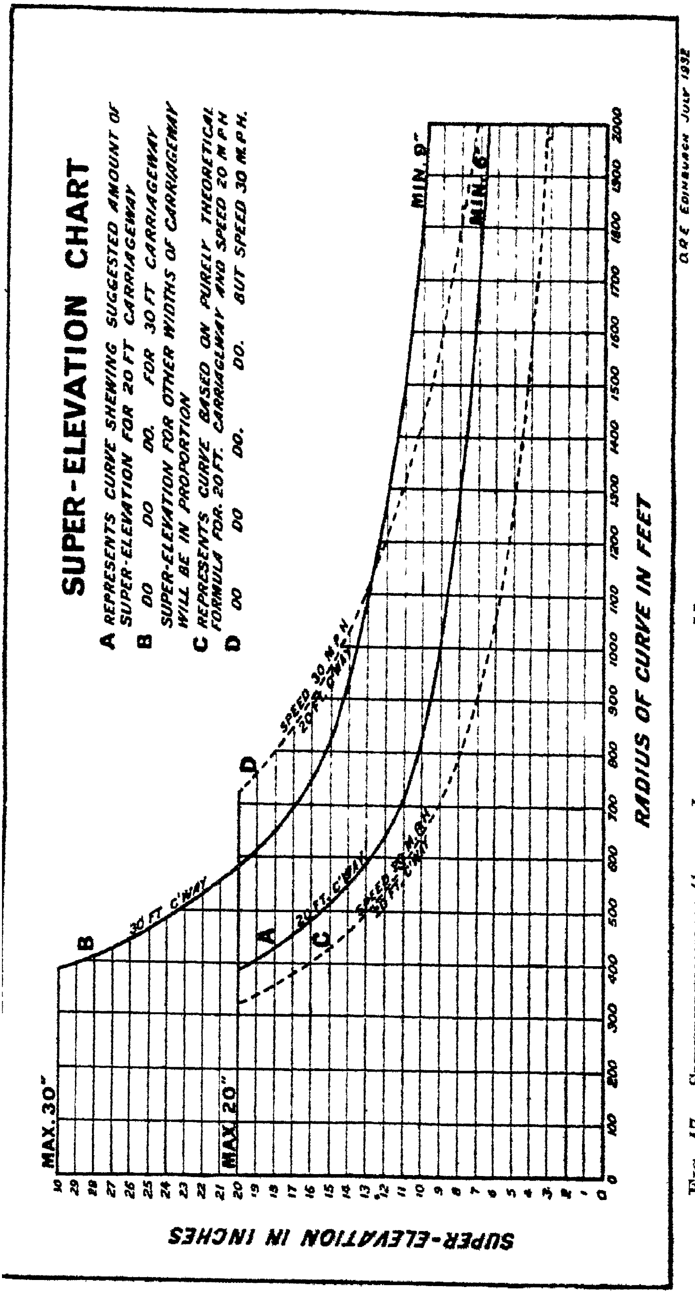


FIG. 47.—SUPERELEVATION CHART ISSUED BY THE MINISTRY OF TRANSPORT (SCOTTISH DIVISION).

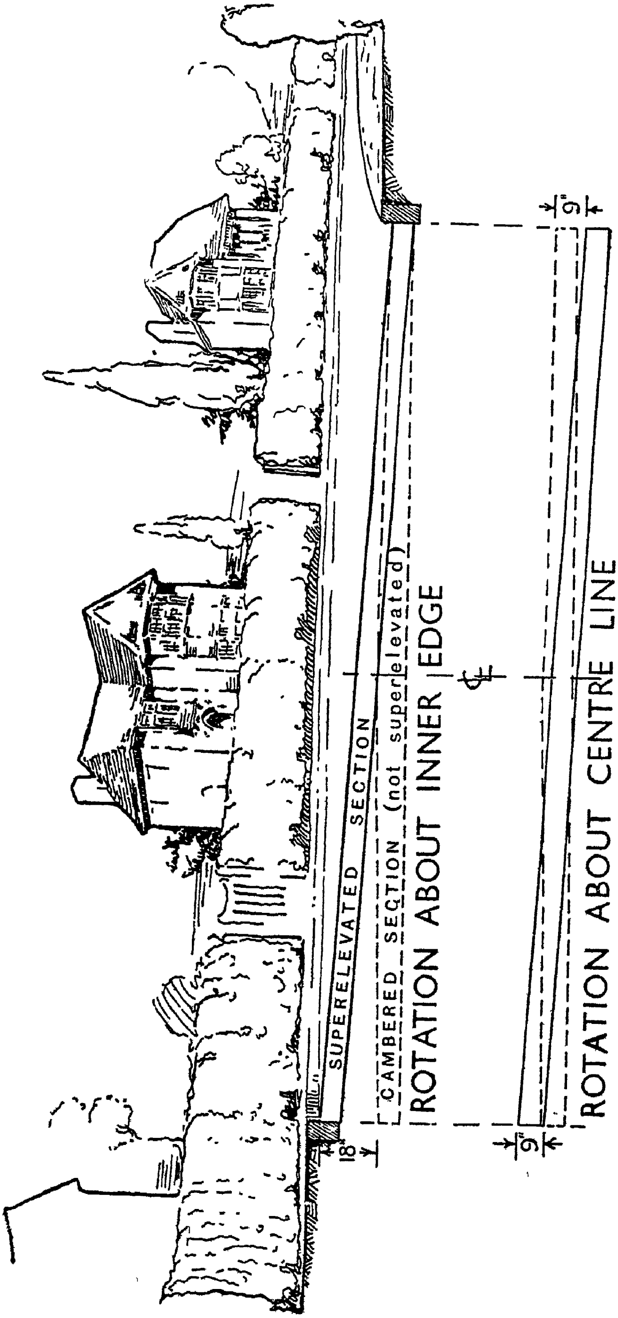


FIG. 48.—METHODS OF EFFECTING SUPERELEVATION BY ROTATION. (*a*) ABOUT THE INNER EDGE. (*b*) ABOUT THE CENTRE LINE (LESS SATISFACTORY).

change should be as gradual as possible. A comfortable rate of rise is obtained by 0·005 ft. per ft. or 1 in 200; generally this should be the limit for the slope of the outer edge of pavement with respect to the profile of the centre line.

Where the transition curve connects with a circular curve, about half the length will be taken up in bringing the crown section level. A typical example of a spiral transition curve is shown in Fig. 49 set out with offsets at 10-ft. intervals.

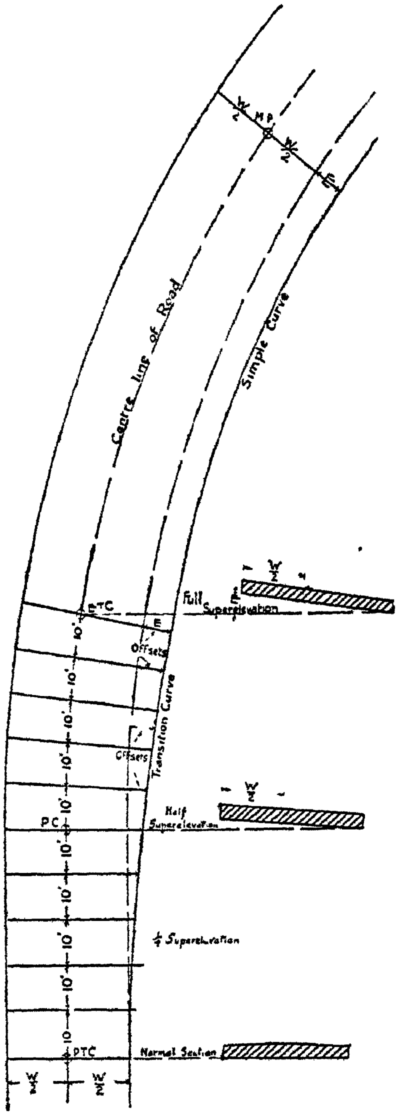


FIG. 49.—TRANSITION BY SPIRAL AND SIMPLE CURVE, SUPERELEVATED.

It sometimes happens that two curves are connected with a short length of straight road; in such cases it is desirable that a crossfall of, say, 1 in 24 to 1 in 60 should be retained to simplify the superelevation on the curves themselves.

To set out the road levels, outer forms and centre forms with pegs to mark the grade should be provided; in particular, this is essential for concrete construction.

If half the superelevation of 1 in 10 is applied through a length of 60 ft., with a road width of 30 ft., this will raise the outer edge at P.C. $\frac{1}{20} \times \frac{15'}{1}$ = 9 in. above the centre line. Assuming that the channel at the normal section is 4 in. below the crown, the maximum gradient due to change of section would be 1 ft. 1 in. in 60 ft., or approximately 1 in 55. This change at the edge of the road is suitable for speeds not exceeding 25 m.p.h. With higher speeds the length of the transition should be increased and the rising gradient flattened to a rate of 1 in 200 if possible.

As mentioned elsewhere, the lemniscate provides perfect conditions for introducing and increasing or decreasing the superelevation according to the rate of curvature.

Superelevating and Widening Existing Roads at Minimum Cost.

There are many cases of road-curves in this country where considerable improvements could be made at comparatively little expense. As previously shown, one of the greatest dangers at cambered bends is that of the traffic in both directions seeking the inside of the curve, so that if the outer section of the road can be improved by raising, even slightly, this danger may be eliminated to a large extent. Also it is possible, where widening is carried out, to raise the surface rather quickly on the outside and to lower it on the inside widening. By this means the existing formation need not be seriously interfered with, while superelevation will be obtained in a simple manner.

The arrangement meets the suggestion that the rate of superelevation might be varied in the cross-section, so that vehicles could choose their own banking according to their speed. For instance, where a vehicle is travelling at a high speed, the tendency is for the driver to continue along the tangent, and this would be checked as he traversed the outer curve, whilst the inner curve would offer similar accommodation for traffic proceeding in the opposite direction.

Variable Crossfall—Advantages.

As will be seen from the example in Morocco, a variable crossfall will accommodate different speeds and types of traffic; for lightly trafficked roads this is a distinct advantage, since drivers of vehicles can utilize the crossfall to suit their needs.

Where there is reluctance to adopt a greater rate than 1 in 12, a variable slope with the main part of the cross-section at that rate might be acceptable.

In hilly districts the increased slope would be placed on the inner or the outer part of the curve, as the case may be, to assist the faster traffic travelling downhill; examples are shown in Fig. 57; also a general case showing an increased slope at inner and outer edge which could be adopted with confidence.

Treatment of Road Junctions.

It is distinctly advantageous to introduce some superelevation at Y junctions of important roads. Two examples are shown in Figs. 50 and 51; in the first case the crown is carried from the centre of the road before it forks to the outer edge of each of the two

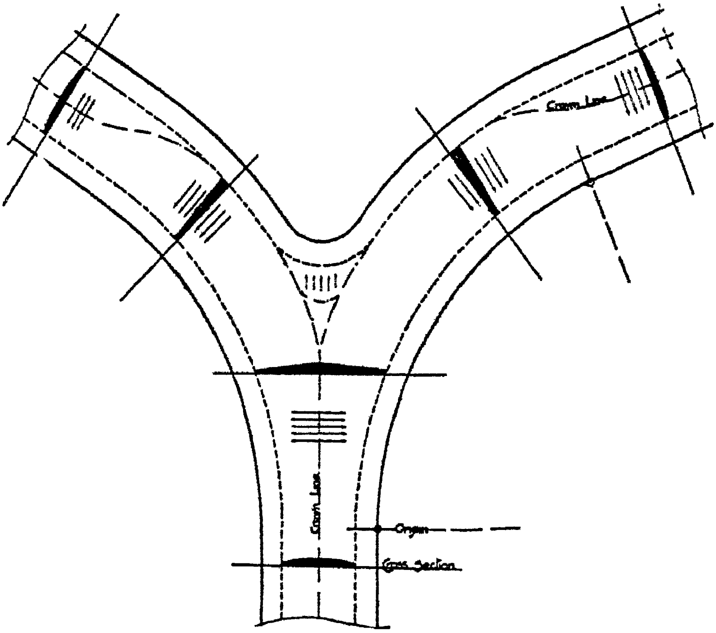


FIG. 50.—SUPERELEVATION AT Y JUNCTION.

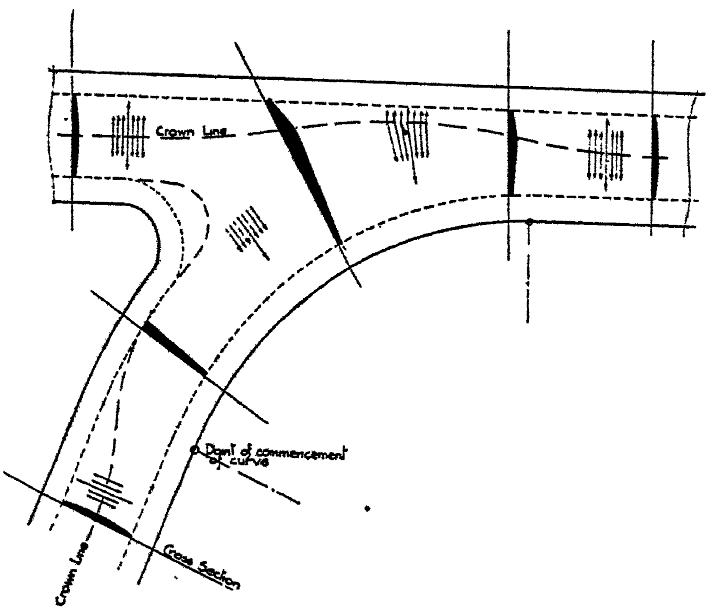


FIG. 51.—METHOD OF BANKING AT OBLIQUE JUNCTION.

branches; in the second case the branch road joining the main road is superelevated and the raised outer edge is made to finish at the intersection of the crown in the main road.

Although speeds may not be great at junctions of this kind, and controls may be introduced by signals, halt signs or even right-angled junctions, there are many roads where conditions are favourable for this treatment.

Difficulty of Superelevation in Towns.

In town areas, where speeds are restricted and practical difficulties exist, the necessity for banking may not seem so urgent; levels of footpaths, steps, and access to buildings create special problems.

Nevertheless, with a growing tendency to prohibit parking of

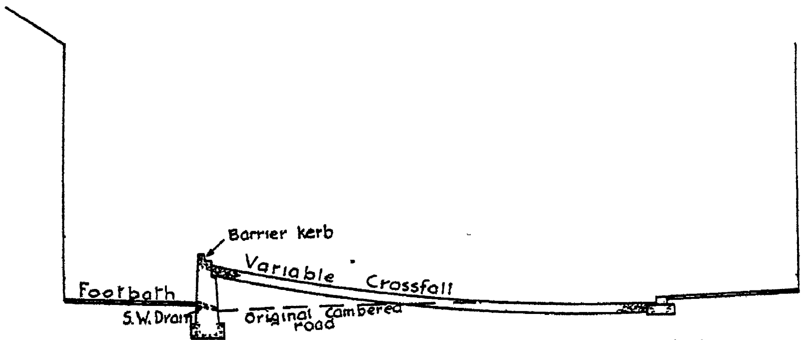


FIG. 52.—METHOD OF SUPERELEVATION IN TOWN (BUILT-UP) AREAS.

vehicles on busy streets, it is possible to raise the kerb height by constructing a concrete retaining wall, with a substantial guard upon it, in order to gain the necessary superelevation. The wall acts as a fence to protect pedestrians.

An example of this is shown in Fig. 52.

There are many other cases, where the footpath at the outer curve may be raised without detriment to adjoining development; this would allow access to the carriage-way, although if it is not practicable to raise the level of the footpath, the retaining-wall method should be adopted; in any case, access to a road at a curve is undesirable.

Economy of Surface-water Drainage.

When roads are banked, gullies are placed on the inside of the bend, thus effecting some economy as compared with cambered straight sections. On new housing estates with curved roads superelevation is often neglected.

It is comparatively easy to arrange the footpath and step levels with new work, and the economy effected in the length of surface or cross drains and in the number of gullies will be found to be quite appreciable. By arranging a deep kerb on the inside and a shallow one on the outside, the difference in level of the two footpaths may be reduced to small dimensions.

American Practice

Superelevation.

The American Association of State Highway Officials recommend a maximum rate of 0·12 ft. (1 in 8·33) per ft.; with snow and ice conditions 0·08 ft. per ft.—i.e. 1 in 12½; for down ramps at interchanges of level provision for higher speeds must be made; the gradient of the outer edge relative to the centre line should not exceed 1 in 200.

Minimum Radius of Curvature.

These are given in the following table :—

Assumed design speed (m.p.h.).	Radius of curvature.	
	Desirable minimum (ft.).	Absolute minimum (ft.).
30	290	230
40	520	410
50	820	640
60	1,150	960
70	1,910	1,430

The absolute minimum is based on the practical maximum superelevation and safe value for the side friction factor of 0·16 for speeds of 60 mp.h. and 0·14 for speeds of 70 m.p.h.

Transitions.

These should be applied where the offset from the circular is greater than 1 ft. for a transition of the required length as determined by the formula.

Superelevation should be attained within the limits of the transition with a maximum gradient at the outer edge (relative to the centre) of 1 in 200.

Grading.

Long grades should be broken by short lengths of a lesser grade; with long gradients which slow down vehicles, additional lanes at

certain places should be provided to facilitate passing, particularly by passenger cars.

Sight Distance (Two or Three Lanes Highways).

This is classed as sight distance (*a*) for stopping, and (*b*) for passing; (*a*) is measured from the driver's eyes, assumed to be $4\frac{1}{2}$ ft. above the pavement surface to an object 4 in. high on the road, (*b*) is a similar height for the driver, but the object is $4\frac{1}{2}$ ft. high on the road.

Alignment.

In the selection of a route for a new highway it is important to make provision for future widening; sudden changes of direction should be avoided, and curves should be of transitional type. A single curve from the straight is more dangerous than a series of curves of the same radii.

In flat country long curves of large radius should be used, rather than long tangents and sharp curves.

French Practice

Early French practice recommended a rate of banking of from 3% to 6% for large curves, increasing to 8%, or approximately 1 in 12, at the outer radius.

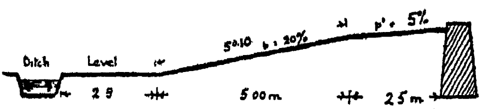


Fig. 53.—Superelevation on the Salé to Meknés Road, Morocco.

It was further recommended that an earth margin should be added at the outer edge of the paved roadway of the curve.

It is useful to note the method adopted on the Meknés road in Morocco. The rate of crossfall is 1 in 5—a value much in excess of normal practice to-day; at the lower edge of the banking the road is practically flat for a width of 2·5 metres while the outer part of the curve, also 2·5 metres wide, has a slope of 1 in 20. Thus "fast" and "slow" traffic is accommodated (Fig. 53).

German Practice

In the design of the German autobahn the minimum rate of superelevation was 2% and the maximum 8%; in 1942 this was

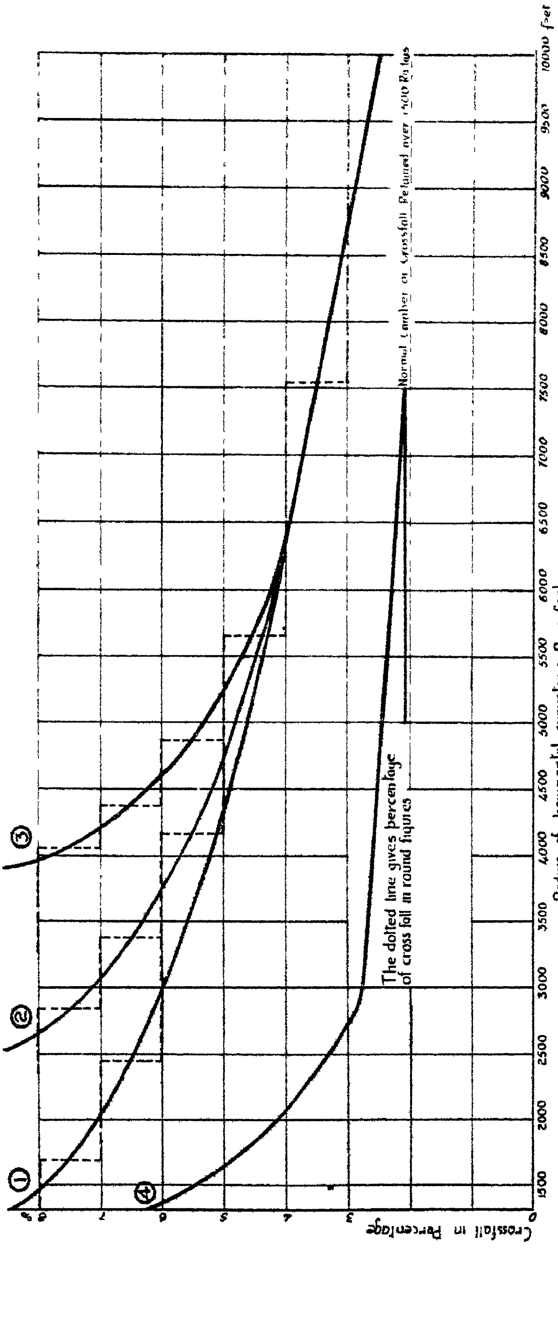


FIG. 54.—DIAGRAM SHOWING SPEED VALUES IN DESIGN OF GERMAN AUTOBAHN RELATIVE TO CURVATURE AND FRICTION. (1) V = 75 M.P.H. (2) V = 87 M.P.H. (3) V = 99 M.P.H. MINISTRY OF TRANSPORT RECOMMENDATIONS (MEMO NO. 575) ARE SHOWN BY (4).

reduced to 6%. The minimum radius of horizontal curves varies from 1,650 ft. to a maximum of 6,600 ft., the former being for high mountain terrain and the latter for lowland country.

In calculating safe speeds, a value for the coefficient of friction f was assumed; a low value was used for large radius curves and high speeds, and a higher value for sharp curves and lower speeds in the mountainous regions.

Fig. 54 shows the speed values relative to different radii of curvature, and three different values for f.

CHAPTER VII

THE DESIGN AND IMPROVEMENT OF HILL ROADS

THERE is a vast field of work to be done in effecting improvements on existing roads in hilly country Many roads in this type of country follow early occupation roads, and financial considerations prevent the construction of new roads or diversions. It will be useful, however, to review features of design for application where practicable to works of improvement of existing highway routes.

Drainage.

The surface drainage of steep hills should be planned to avoid damage to the road surface by the high velocity of flow in storm periods.

With a minimum camber, water will flow some distance before reaching the channel; in these circumstances there is a danger of some road material being washed out and a channel formed; disintegration of road surfaces caused by "frost-and-thaw" conditions makes the scouring action more likely to occur. Ample provision should be made to pass channel drainage into ditch drains of sufficient depth to prevent water running back on to the road. In particular, outlets from the channels should always be provided at the tangent points of curves; if ditch or side drains are piped with steep gradients, these will provide a high discharge capacity, and the necessity for maintenance of the ditch is avoided.

In addition to surface drainage of the road, water may be received from the "up" side of a road or from both sides in the case of a cutting; much depends on the nature of the subsoil and the run-off area.

Where banks are liable to wash away, rubble drains (such as may be observed in railway cuttings) are useful for guiding storm-water to the base without erosion.

Paved channels, with setts or concrete, are effective in resisting scour; on the "up" side the channel may require extra width.

Where gullies and grids are used—e.g. in urban areas—ample grating area must be provided; grids with suitably curved bars help to intercept rapidly flowing water.

Drainage at "Valleys".

It is essential to provide ample drain outlets at points where the two opposing gradients form a valley. This may be done by

(*a*) constructing a sufficient open culvert, bridged, or a large pipe under and across the road, to flow away, (*b*) using a smaller pipe for normal flow and allowing flood-water to pass over a paved surface, slightly dipped, which thus temporarily becomes a ford; this is suitable only for light traffic volumes and reduced speeds.

An example of this kind of construction is shown in Fig 55

Generally where the road is running transversely across sloping

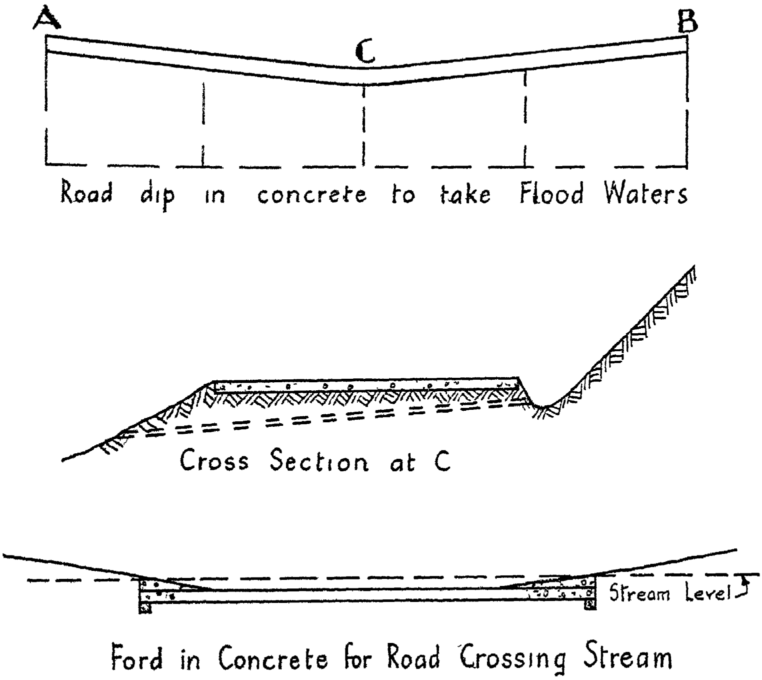


FIG. 55.—DESIGN OF FORD (WITH DRAIN BENEATH) TO TAKE FLOOD WATER.

ground, cross drains should be laid at intervals to avoid too much concentration at any one point.

The character of the subsoil will affect the natural flow beneath the road; a gravel or sandy subsoil will help to syphon the water by capillary attraction from the upper to the lower side of the road. It should be mentioned here that the dry, sandy soils which occur in hot climates have a relatively high load-carrying capacity because water drains away readily.

Design Speeds for Mountainous Roads.

It is desirable to have a reduced value of speed for design purposes for roads in mountainous countries; this in turn will depend on the

density of traffic using the road daily; in the nature of things the volume of traffic in hilly regions is usually very limited

Where the number per day is less than 100, lower design speeds (say 20 m.p.h.), sharper curves and gradients are permissible; similarly, in these circumstances it is practicable to allow for narrower widths of carriage-way and of bridges.

Where the volume is between 500 and 1,000 vehicles per day, the maximum gradient should not exceed 7% or 1 in 14, while the design speed might well be assumed between 30 and 40 m.p.h. and road widths from 24 to 30 ft.; curvature at bends should be of a larger radius for the higher-design speeds.

A ruling gradient of 1 in 30, as practised in the building of the Telford roads, creates comfortable travel conditions where this can be achieved. Occasionally it may be necessary to break the rule for the design gradient and apply a short steep gradient at the commencement of a long climb.

Flat sections on a hilly route are desirable, as they enable a vehicle to regain momentum, probably reducing the time taken to mount the hill.

It is estimated that the average speed of heavy lorries on an "up" gradient of 1 in 20 is about 15–16 m.p.h.

Widening for Long Gradients.

Where long hills are a necessity and the width of the road will carry only two lanes, the slow speed of the heavier vehicles frequently causes a "hold-up" of other (lighter and faster) traffic; the A.6 road over Shap, Westmorland, is a good example of this condition.

To counteract the obstruction so caused, it is advantageous to widen a section of the road on the "up" side to create a third traffic lane; this would naturally be formed on the length which proved to be the most easy and economical to construct; thus the slow traffic would pull in to the third lane and enable the following traffic to pass; an example of this is given in Fig. 56.

Vertical Curves for Undulating Roads.

Roads in hilly country afford many opportunities of effecting improvement in sighting distances by introducing parabolic or other curves for summits and valleys.

It is recommended that a minimum sight distance be selected below which it is not advisable for one vehicle to overtake another, this will depend on the average or design speed for the particular road; a minimum figure of 250 ft. for speeds of 30 m.p.h. is suggested; or 300 ft. for 35 m.p.h. for a two-way road; reference to this point is made elsewhere.

German "Hill Road" Design.

The main standard of alignment used on the autobahn was varied in 1942 from the pre-war standards, they now recommend that the maximum gradient resulting from the longitudinal gradient and the crossfall should be 7%—only in exceptional circumstances should it be 8%; Fig. 57 shows the maximum crossfalls up to 8%. The table on p. 85 shows the two standards for lowland, hilly and mountainous country.

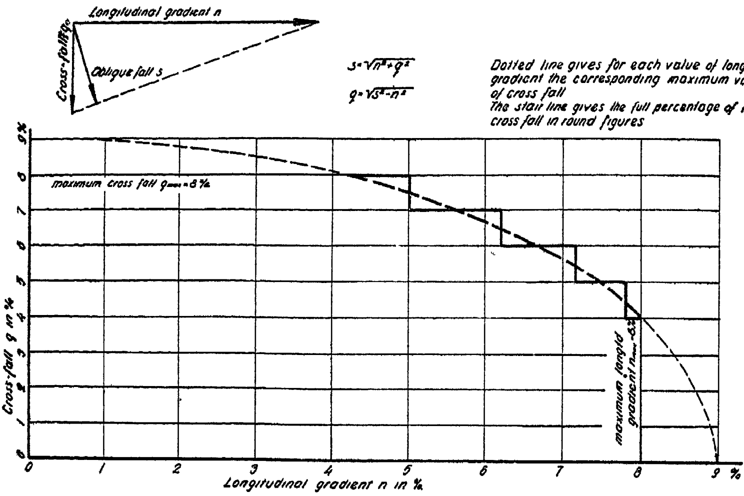


FIG. 57.—CROSSFALLS FOR GERMAN AUTOBAHN.

Hairpin Bends: Reduction of Gradient at Bends.

Hairpin bends occur in mountain districts as a physical and economic necessity.

Superelevation of the road surface at such bends requires very careful consideration; hairpin corners may often be improved by widening on the outside of the bend by filling and banking and by increasing, if possible, the radius of curvature on the inner edge. Where the "up" traffic turns right it is likely to seek the outside of the bend, in order to gain a better gradient. With reverse curves which occur in this type of country similar improvements may be effected as with the single hairpin bend.

Wherever practicable and not too costly, it is advisable to reduce the gradients at all curves on steep gradients or, in fact, on any gradient. The tractive effort for the ascending vehicle is considerably increased in making the turn; to counteract this the gradient should be reduced for the whole length of the curve; thus the speed of the vehicles on the "up" side is more easily maintained; on the other hand, downward traffic will find it easier to reduce speed

STANDARD OF ALIGNMENT USED FOR THE GERMAN MOTOR ROADS
(FROM *Road Research Technical Paper* No. 8)

Item.	1937 specification. Type of country.			1942 specification Type of country			
	Lowland.	Hilly.	Mountain.	Lowland.	Hilly.	Mountain.	High mountain.
Assumed maximum speed m p.h.	100	90	80	100	87 5	75	62·5
Maximum gradient	4% (1 in 25)	6% (1 in 16$\frac{2}{3}$)	8% (1 in 12$\frac{1}{2}$)	4% (1 in 25)	5% (1 in 20)	6% (1 in 16$\frac{2}{3}$)	6·5% (1 in 15$\frac{1}{2}$)
Minimum radius of horizontal curves	1,800/2,000 m. (5,900/6,600 ft.)	800/1,000 m. (2,600/3,300 ft.)	600 m. (2,000 ft.)	2,000 m. (6,600 ft.)	1,200 m.[1] (4,000 ft.)	800 m.[1] (2,600 ft)	500 m [1] (1,650 ft.)
Minimum radius of vertical curves : Summit	16,700 m. (55,000 ft.)	9,000 m. (29,500 ft.)	5,000 m. (16,400 ft.)	20,000 m. (66,000 ft.)	12,000 m. (40,000 ft.)	8,000 m. (26,000 ft.)	8,000 m [2] (26,000 ft.)
Depression	5,000 m. (16,400 ft.)	3,000 m. (9,800 ft.)	3,000 m. (9,800 ft.)	10,000 m. (33,000 ft.)	8,000 m (26,000 ft.)	6,000 m (20,000 ft.)	6,000 m [3] (20,000 ft.)
Minimum sight distance	280 m. (920 ft.)	250 m. (820 ft.)	160 m. (525 ft.)	300 m. (1,000 ft.)	250 m. (820 ft.)	200 m. (660 ft.)	150 m. (500 ft)

[1] Curves having radii of down to half these values are allowed in exceptional circumstances.
[2] 5,000 m. (16,400 ft.) allowed in exceptional circumstances.
[3] 4,000 m. (13,000 ft.) allowed in exceptional circumstances.

when passing the bend. Incidentally, where this is done the reduction of gradient helps to reduce wear on the road surface at the curves.

Types of Surface for Hill Roads.

A road surface that is non-slip in wet weather is desirable for all types of road; in particular, however, a reasonably non-slip even surface is essential for safety where gradients occur. A fine-texture tarmac surface may be avoided by using a coarse-graded chipping $\frac{1}{2}$–$\frac{3}{4}$ in. in connection with tar-spraying.

Cement-bound macadam is a type of construction which provides a non-slip surface which is retained under the action of traffic and weather.

Concrete road surfaces of similar finish to roads in level country provide safe running for traffic; special tamped or crimped finishes may be applied to afford a better grip for driving-wheels and for braking.

In the past, grit setts have been used to provide a non-slip surface, but this type of construction has now been abandoned in favour of more even surfaces.

Wheelers.

The practice of laying granite or stone blocks known as "wheelers" on the "up" side to ease the tractive resistance for horse traffic on the "up" side has much to commend it; the wear from driving-wheels is resisted by the hard-wearing surface provided. The blocks should be laid on concrete, at about 4–5-ft. centres, 15–18 in. wide, and about 4 ft. long; otherwise the wheelers may be paved with concrete laid *in situ*; the space between may be paved with setts or tar macadam.

Where there are three lanes, slow, heavy traffic will tend to keep to the extreme left by travelling on the wheelers laid in that position.

Superelevating Dangerous Bends on Hill Roads.

Banking of sharp bends on roads having steep gradients should now be normal practice; the importance of this concerns more particularly the traffic proceeding downhill. Existing roads which are insufficiently banked can be improved on the down side by either of the methods shown in Fig. 58. Where the "down" traffic travels on the outside of a bend—i.e. makes a right-hand turn—the rate of superelevation may be made variable, so that a much steeper banking is provided towards the outer edge of the curve or roadway.

Hill Approaches to Main Roads

It frequently happens that a steep branch road meets or crosses a main road which runs on the contour of the hill. In such cases there is a danger of " down " traffic over-shooting the main road from the upper side and of running back when halting on the lower side. It is desirable to reduce the gradient of the secondary or branch road

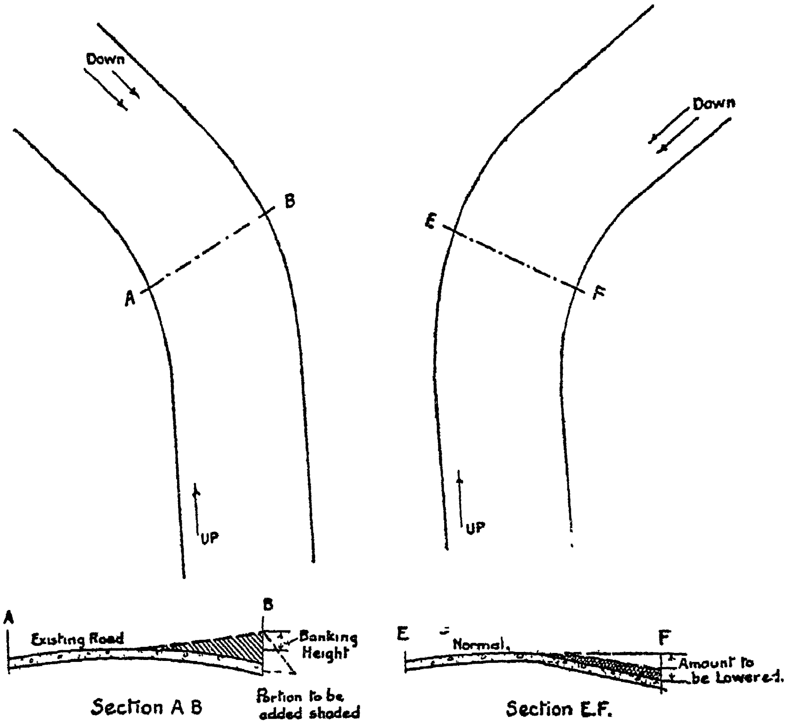


FIG. 58.—SUPERELEVATION OF DANGEROUS BENDS.

for a short distance prior to the actual intersection, as shown in Fig. 59. An additional advantage may be obtained by widening the main road near the intersection, as this will allow a certain amount of filtering or turning while keeping the main road clear for through traffic.

Landslides.

Landslides usually occur where weathered or frost-exposed shales or alluvial deposits overlie the bedrock. Slipping planes on which the earth moves are about $\frac{1}{16}$ in. thick, and often have a greasy nature like the " slicken sides " met with in the coal measures.

Methods of dealing with slips by retaining walls and by excavating

are costly, although in some cases inevitable. Slips may be controlled by one or more of the following methods :—

(a) By drainage; if ditches are cut into the solid, cracks and holes sealed and pools drained by surface ditches, the slip should dry up.

(b) By piling, when a slip is on solid rock

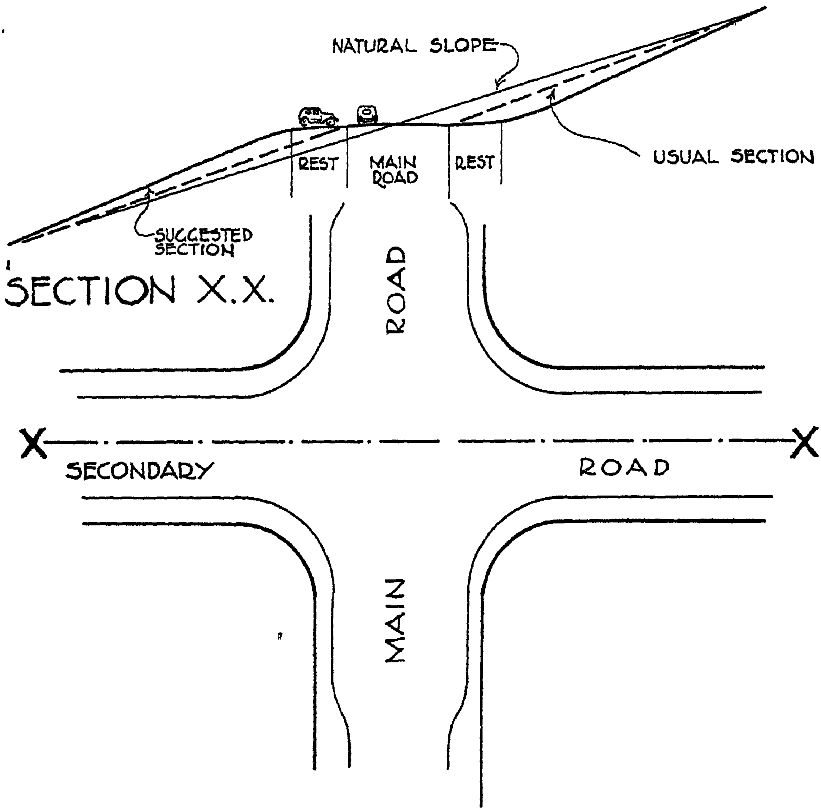


FIG 59.—HILL APPROACHES TO MAIN ROAD.

(c) By ribbed walls of concrete or timber for shallow slips, or casting a concrete grillage on the upper slope to keep out water.

(d) By perforated corrugated or porous concrete pipes laid on the inside of the road, or deep rubble drains.

(e) By blasting the rock-base to give frictional resistance against slipping.

(f) Where the road has lifted, to build it up with new material to counteract the upward pressure.

(g) To build a reinforced-concrete road on steel piles driven into the bedrock.

In more serious cases of a road-slip due to a general movement, diversion of the road, although costly, may be the best method of dealing with a troublesome landslide

Cattle-grids.

The provision of cattle-grids forms a useful and economical method of preventing sheep and cattle from straying along an open road where there are otherwise boundary fences crossing the direction of the road; this prevents the animals from straying from the adjoining fields.

The Highways (Provision of Cattle) Act now authorizes this to be done and by this means, gates (which are never satisfactory) may be dispensed with

The grids will consist of old rails at about 6 in centres or $1\frac{3}{4}$ in. diam. round bars at about $4\frac{1}{2}$ in. centres, the width will vary from about 8 ft to 20 ft. and the length should be about 8 ft. 6 in. The pit below should be about 2 ft. deep; a short by-pass road and gate may be provided to cater for horse-drawn and very heavy loads and possibly a "clap gate" for pedestrians Suitable warning signs should be erected to guard the crossing.

Route Location and Aerial Surveys

In a highly developed country like Britain the art of route location may not now receive the attention which it deserves, and certainly not the care and attention which were devoted to the selection of the best routes for the railways. There are two aspects in this matter so far as roads are concerned, viz. (*a*) the economic, and (*b*) the amenity aspect.

In flat country the location of route for main or by-pass roads presents no great difficulty: yet one should have regard to the existence of trees and woods, which can often be brought into the limits of the road frontage without unduly increasing the cost of construction as compared with a line based solely on a minimum cost and straight lines; reconnaissance surveys of a proposed route and of alternatives are essential to determine the best and final location.

Even if the cost is appreciably greater, it should be measured against the advantages of amenity and additional service by reason of its greater length.

It is not proposed in this volume to deal with the details of tacheometric surveying and levelling required for the purpose: alternative routes should be carefully studied from all points of view; questions of gradient and drainage are naturally of major importance.

A gently undulating road with a good range of vision and easy vertical and horizontal curves is capable of making a most attractive highway; long straight lines are less objectionable where the summits limit the visible alignment; all summits should offer a long range of vision. Except in very difficult hilly country, curves of long radius should be selected (see German autobahn practice, table on p. 85).

Aerial Surveys.

Aerial survey work and photography formed a most important part of aerial warfare and, in fact, for warfare generally, and great advances in technique and application were made during the last war. It is now a comparatively simple matter to have an aerial survey made, if required, of a whole district to help in the selection of sites for new communities or industrial estates; it is desirable that photogrammetric maps made from aerial surveys reduced to $\frac{1}{4}$–1 mile strips, should show contours with a reasonable accuracy. The Ordnance Survey of Great Britain with contours is, of course, available for all parts of the country, and road-planning from the 1/2,500 or other scales presents no difficulty in the preliminary stage. As, however, many areas have not been revised for some years, aerial surveys may be utilized with advantage: periodic surveys from the air are useful in recording the development of a town or country, and these may include a bird's-eye view and photographic record of the traffic on the various main roads.

The final location of a line of road, made either by aerial survey or by trial and error, will be made by the engineer after taking cross-sections and determining suitable tangents and curves and excavation and filling (by the " end-area " or other method).

The preliminary location of the line will become the final location after setting out on the ground and making the necessary minor adjustments.

CHAPTER VIII

TRAFFIC SURVEYS

TRAFFIC surveys are carried out from time to time to determine the present traffic usage and to forecast the trend of traffic for the future; this enables one to estimate the trend of highway expenditure.

A general traffic census taken throughout the country enables much useful information to be collated; this may be detailed as follows:—

1. To determine the average daily volume of traffic and its nature and destructive effect on the highway.
2. To determine the variation in volume and congestion at different periods of the day, week, month, or year, and from year to year.
3. To estimate probable speeds and spacing of vehicles.
4. To determine the difference in volume and traffic characteristics before and after an improvement.
5. To enable the cost of road maintenance per vehicle to be assessed.
6. To assist the engineer in designing, maintaining, or reconstructing a highway.
7. To assist the police in selecting signal or other control points.
8. To assist in the preparation of highway planning in town-and-country planning schemes.

Where previously traffic was counted by enumerators stationed at selected points, mechanical traffic counters are utilized (portable inexpensive non-recording counters are now available). One type of vehicle detector consists of a rubber tube stretched across the road and secured to it at 3-ft. intervals by clamps; air pulsation and a diaphragm operate an electro-magnetic counter.

Photo-electric counters can be placed to operate continuously over a long period; these will supply hourly data, and so indicate traffic trends.

Check-weighing of Vehicles.

This may be carried on by fixed weighing-stations or by portable jack recorders for testing wheel-loads.

It is also useful to obtain information concerning heights, lengths, widths, and other details of vehicles, particularly heavy vehicles and buses; this data is of value in designing foundations and road surfaces; moreover, it shows the trend of development.

Before and after Traffic Studies.

The Road Research Laboratory has developed methods for measuring traffic flow and speed, and stationary vehicle concentrations (e g. at traffic lights).

The "moving-observer" method is used on a two-way road by filtering a test car into the traffic being studied; the observers record the flow of traffic relative to the car when moving against and also with the stream. They record also the journey time of the car in each direction and full details of intersections, etc. The results of flow may be checked with those of a stationary observer.

Directional Traffic Surveys.

For planning purposes, directional traffic surveys furnish the necessary information for the highways development plan.

The methods employed are either (1) by direct questioning of drivers of vehicles; or (2) by recording the registration numbers of vehicles. In dealing with an existing town, one is able to assess the probable routes of vehicles assuming the proposed new roads were in existence.

The destination of vehicles is found by stopping vehicles at selected points, and, in addition to checking the internal movements within an area, the full details of all vehicles entering or leaving the area must be taken. The whole of the data requires to be analysed, a procedure which meets considerable time and care.

Maps and Traffic Data.

Special maps showing all roads and community development are useful for research work on road-traffic problems. Diagrams can be used to indicate the density of traffic on particular sections of each main road, density of traffic being shown by heavy lines, to scale, varying in width according to the number of vehicles plotted These diagrams are useful in determining immediate trends of traffic.

There is a wealth of other information which should be noted in this connection; for example, registration of motor vehicles and their garage location, weights and ton-mileages, consumption of petrol, road widths and construction and maintenance costs.

By-passing of Traffic.

It is always a little conjectural as to the proportion of traffic which would use an adequate by-pass road if such were available.

The diagram in Fig. 60 shows the estimated proportions of traffic (based on traffic surveys for seven cities in the United States of

50,000–100,000 population) which could be by-passed. The high proportion entering the central business area creates problems which can only be solved at enormous cost A good example of a scheme to solve this kind of traffic congestion is the Houston (Texas) freeway. The traffic congestion of London can only be solved by major schemes of this kind.

On the other hand, it may be desirable to consider proposals for creating car-parking areas on the fringe of the city area and the provision for transporting passengers (car drivers) by cheap electric

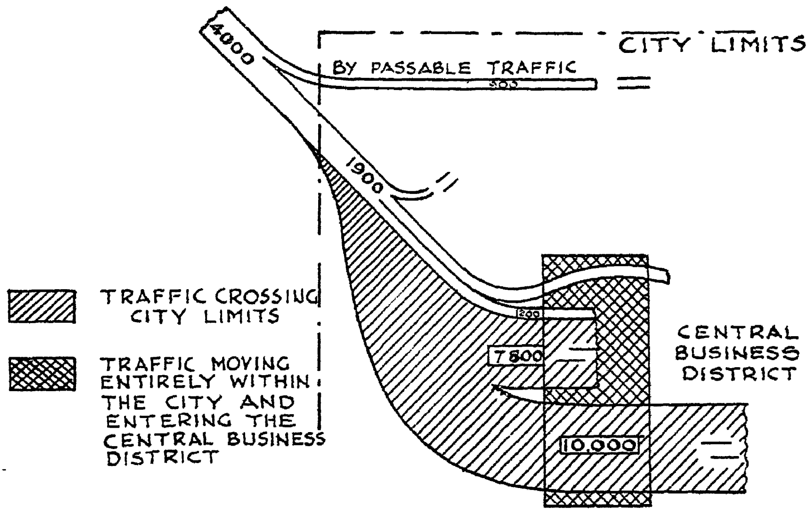


FIG. 60.—U.S. TRAFFIC SURVEY OF SEVEN CITIES SHOWING METHOD OF DIAGRAMMATICAL PRESENTATION.

rail transport—preferably with flat charges for travel—or bus travel from the " fringe " car park into the central area.

When by-pass roads have been constructed around small towns, the traffic carried has generally increased considerably as compared with that on the old road passing through the town; examples of this may be found at Sidcup, Colnbrook, Daventry, and Hessle.

Hourly Variation of Traffic.

The determination of the frequency of traffic at different periods of the day or week will enable the engineer to record the most congested part of the time that the road is under observation. In taking an hourly census the figures can readily be tabulated and totalled for daily comparisons. A typical pre-war hourly census on a busy main road is shown in Fig. 61.

The record on some days of the week will show a heavier volume

of traffic than others. In some cases the week-end traffic, though of a different nature, will be much greater than normal week-day traffic.

The records will also show that at certain parts of the month the traffic will be heavier than at others Hourly variations, shown by the records, will enable the engineer to estimate approximately the

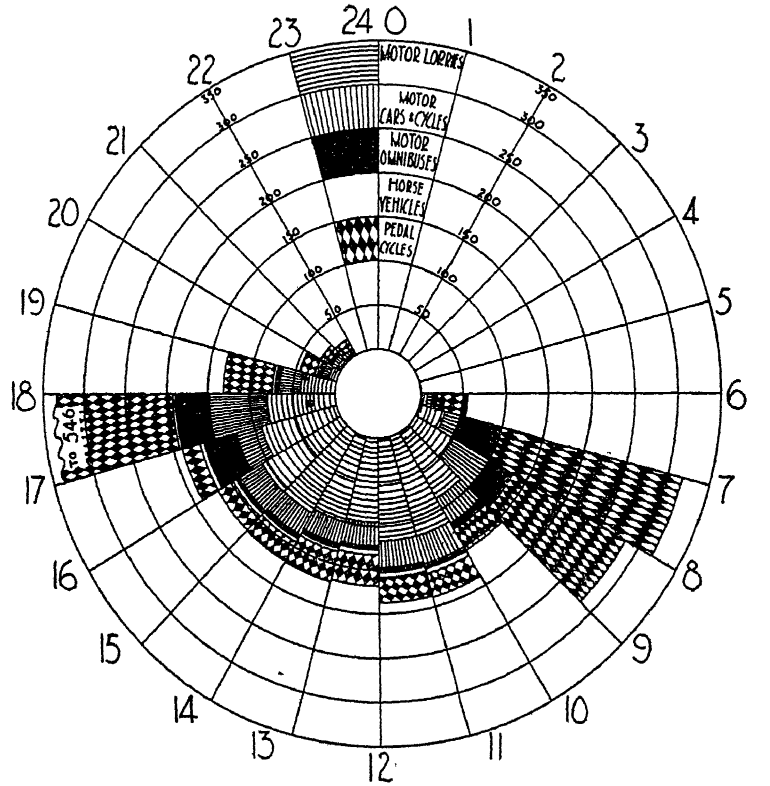


FIG. 61.—DIAGRAM SHOWING HOURLY VARIATION OF TRAFFIC.

average distance between those vehicles running in the same direction. This information may be supplemented by records of the actual speed of vehicles where circumstances warrant it.

In all cases of periodical census of traffic the weather conditions should be noted, so that no unequal comparisons are made.

Seasonal Variation of Traffic.

Seasonal variation of traffic is perhaps of the greatest importance to the road authorities, as there is a vast difference between traffic

in midsummer and traffic in midwinter. Where records are kept monthly, a fairly accurate register of the seasonal variations may be secured. Failing monthly records, a quarterly census—taken, say, in the months of January, April, July, and October—will give a fair estimate of the change taking place. It will be realized from this comparison that the road surface is very much more subject to wear during the summer than in the winter, so far as the traffic is concerned.

Average Annual Traffic Volumes.

The method adopted in the United States for an engineering analysis to determine the practical capacity of a particular road is to relate the thirtieth highest hourly volume to the average annual daily traffic volume, taken over a wide area. The table below gives the capacities of two- and four-lane highways on an annual basis, given ideal conditions including 12-ft. lanes, tangent alignment and uninterrupted flow.

TABLE RELATING AVERAGE ANNUAL TRAFFIC VOLUMES TO PRACTICAL CAPACITY OF DIFFERENT TYPES OF HIGHWAY (FROM NATION-WIDE TRAFFIC SURVEY)

Type of traffic.	Average Annual Daily Traffic (volume in vehicles per day).					
	Two-lane rural roads.		Four-lane rural roads.		Four-lane urban express highways.	
	Level terrain.	Hilly.	Level terrain.	Hilly	Level terrain.	Hilly.
Passenger vehicles only . .	5,750	5,750	19,250	19,250	37,500	37,500
Passenger vehicles with 10% commercial vehicles .	5,200	4,450	17,500	14,800	34,000	29,000
Passenger vehicles with 20% commercial vehicles	4,800	3,600	16,050	12,000	31,000	23,500

Speed Affects Spacing.

At high speeds more clearance between vehicles is necessary for safety; indeed, it can be shown that the number of vehicles passing a given point on a two-lane highway at 45 m.p.h. is no more than the number which would pass at 25 m.p.h.

If 1,000 vehicles pass a given point in one hour at a speed of 20 m.p.h., the average spacing centre to centre would be 150 ft.; this

is equivalent to 2,000 vehicles per hour on a two-lane highway. Observations show that there is no serious congestion on two-lane roads with 1,000 vehicles per hour or on three-lane roads with 1,600 vehicles per hour; naturally commercial vehicles tend to reduce the capacity.

Maximum Capacity of Roads.

Under ideal conditions, however, the maximum possible capacities are as follows :—

Two-lane highways—2,000 cars per hour (total in both directions).
Three-lane highways—4,000 cars per hour (total in both directions).
Four or more lane highways—2,000 cars per hour per lane.
(These figures are based upon 12-ft. lanes—U.S. Standard.)

The above volumes occur at a speed of about 30 m p.h ; speeds higher or lower than this will reduce the capacity, this is shown in the graph in Fig. 62.

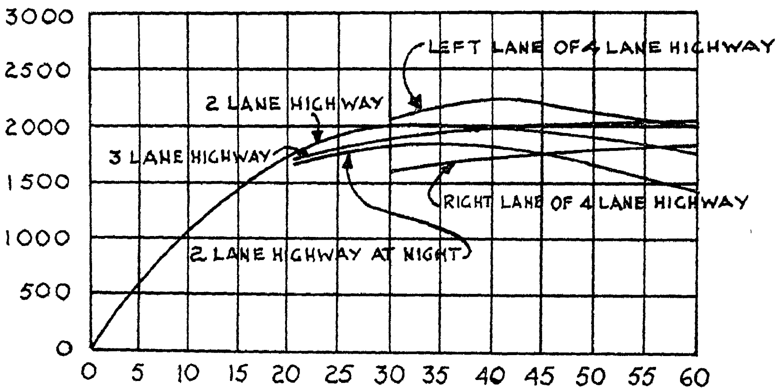


FIG. 62.—GRAPH SHOWING MAXIMUM CAPACITY OF A TRAFFIC LANE, BASED ON AVERAGE SPACINGS BETWEEN PAIRS OF VEHICLES TRAVELLING AT THE SAME SPEED.

It should be noted that these figures are peculiar to America, where main roads are protected from all branch roads by " STOP " signs.

Effect of Narrow Lanes.

The width of lanes in Britain is 11 ft. for two-lane and 10 ft. for three-lane; this reduction will reduce the capacities shown, especially as the 12 ft. width is better able to accommodate heavy commercial vehicles.

Clearances between the edge of the road and vehicle obstructions such as bridge abutments, retaining walls, or parked cars affect the carrying capacity of a normal two-lane road; also the occasional breakdown on the roadway reduces capacity immediately.

The table below gives the practical capacity for lane widths between 9 and 12 ft

Lane width (ft.).	Three-lane rural roads.	Multi-lane motorways.
	Percentage of 12-ft. lane capacity.	
12	100	100
11	86	97
10	77	91
9	70	81

Traffic Values for Rural Areas.

In connection with the preparation of the Development Plan, the Ministry of Transport Memorandum No. 653, the Ministry of Transport has specified certain values for traffic density for the design of rural roads as follows.

Two-lane highways . .	Up to 300 vehicles per hour.
Three-lane highways .	From 300 to 600 vehicles per hour.
Dual two-lane highways .	,, 600 to 1500 vehicles per hour.
Dual three-lane highways.	Over 1500 vehicles per hour.

(In the first two, one cyclist counts as one vehicle, and in the last two, two cyclists count as one vehicle.)

The Thirtieth Highest Hour for Traffic.

Road planning in other countries is based on a rate of hourly traffic which occurs at least thirty times a year; in other words, the thirtieth highest hour is taken as the basis, to obtain this considerable traffic census figures are needed, and frequently these are not available.

It is uneconomical to design the average highway for a greater hourly volume than that which is exceeded during only thirty hours each year.

The thirtieth highest hour as a percentage of annual daily traffic ranges from 8% to 38%, with an average of about 15% on rural roads and 12% on urban roads.

Road Widths.

The Ministry of Transport has laid down minimum effective widths for different lay-outs of roads as follows :—

MINIMUM EFFECTIVE WIDTH TO BE ADOPTED

	With footpaths only. (ft.).	With footpath and cycle track. (ft.).
Single carriage-way . .	60	80
Dual carriage-ways (two lanes)	80	100
Dual carriage-ways (three lanes)	100	120

These minimum widths may be increased for special local needs, and for heavy industrial traffic or buses 70 ft. between the outer kerbs of dual carriage-ways is necessary for turning; excess widths may be needed for large embankments and cuttings and in built-up areas.

The design policy of the A.A.S.H O. provides for varying the widths of surfacing on two-lane highways with the type and volume of traffic and the assumed design speed; the minimum widths of surfacing are shown in the following Table.

Assumed design speed (m.p.h.).	Vehicles per hour.			
	5–30	30–100	100–200	More than 200
	(ft.).	(ft.).	(ft.).	(ft.).
30	16–20	18–20	20	22
40	16–20	18–20	20–22	22
50	18–20	20	20–22	22–24
60	20	20–22	22	22–24
70	20	20–22	22–24	24

If shoulders to carry traffic are flush with the pavement, the widths may be reduced by 2 ft.

Where lorries are a normal part of the traffic, a width of less than 11 ft. is undesirable and one of 12 ft. is to be preferred.

The Ministry of Local Government and Planning has issued the following schedule for guidance in the planning of new streets in residential areas.

MINIMUM WIDTHS FOR NEW STREETS IN RESIDENTIAL AREAS

	Minimum width of carriage-way (ft.).	Minimum no. of footways.	Minimum width of each footway (ft.)	Extra for waiting bays (ft.)	Maximum length (ft.).
Main streets	22	2	9 12 (for shops)	8 9 (buses)	Unlimited
Minor streets (shopping street)	22	2	12	"	"
General (through street)	16	2 (1 if access is one side only)	6 12 (for shops)	8	"
Cul-de-sac	13	2 (or 1 as above)	6 (or 4 ft. 6 in plus verge)	—	600
Cul-de-sac	13 (9 ft. if no access to property)	1	4 ft. 6 in.	—	200
Street adjoining open space	13	1	6 (12 with shops)	8	1,000
Street for secondary access	13	—	1 ft. 6 in. margin	—	—
	9	—	"	—	200

Turning spaces should be provided at the closed end of cul-de-sac streets, to allow vehicles to turn in a circle of at least 30 ft. diameter; a "cul-de-sac" notice should be displayed at the entry to the street.

CHAPTER IX

TRAFFIC CIRCLES OR ROUNDABOUTS

TRAFFIC circles or roundabouts are now an accepted inherent part of our road system as a traffic facility for safe treatment of road intersections; the main feature is a central area (which may not necessarily be circular) around which traffic rotates and connects inwards and outwards with the several radial roads.

The advantages of the rotary treatment of intersections are :—

1. A steady one-way traffic movement is ensured.
2. " Weaving " is facilitated for all classes of traffic.
3. A considerable volume of traffic can be kept moving in safety.
4. Right-hand turning is made easy and oblique radial roads are connected with a minimum of alteration.
5. The passage of traffic is quicker than by use of traffic signals, in very busy circles with heavily trafficked roads some of the radial roads may require to be controlled by traffic signals or " HALT " signs.

Size of Circles.

The size and shape of the circle or roundabout are of importance; generally the diameter should be about 180 ft. or more; where the diameter is 150 ft. or less, the speed of traffic will be reduced to 20–25 m.p.h.

Large islands facilitate the " weaving " of traffic at comfortable speeds; dazzle of headlights is less evident, and the radial roads can be divided or diverted with the aid of transition curves and " directional " or separating islands.

Small islands are less desirable, but are useful where traffic is not heavy.

Design Speed.

This depends on the normal speed on the principal intersecting roads; this, in turn, depends on the design of these roads, whether dual carriage-way, the width and so on.

The following table gives a method of determining the design speed on the roundabout, where 70% is taken as the average speed of all vehicles on the main roads.

Main road. speed in m.p h.	30	40	50	60
Average speed at 70% in m.p h.	21	28	35	42
Design speed on roundabout in m p h	25	30	35	40

A roundabout is not justified if the rotary design speed is less than 25 m.p.h. nor if the main road speed exceeds 60 m.p.h.; in the latter case a fly-over junction or "grade intersection" is the solution.

Weaving.

There is clearly a relationship between the size of the central island and the weaving distance between the radial roads. Weaving distance is essential if the smooth flow of traffic is to be maintained. This requires two lanes of traffic, so that a vehicle may cross over from one to the other at a suitable angle within the weaving length. It is clear that unless the diameter of the central island is more than 100 ft. there will be little room for weaving between one radial road and the next. If the volume of traffic is relatively small, then weaving is not important, nor is a large circle necessary.

Gradients.

Longitudinal gradients should be limited on traffic circles and if possible should not exceed 1 in 30; ample sight distance (not less than 200 yd) should be afforded and advance warning signs fixed on the approach roads.

Width of Carriage-way

The width of carriage-way around the centre islands depends on the volume of traffic to be circulated; this, in turn, depends on the number of traffic lanes and of radial roads. With a maximum of twelve lanes—i e. two lanes on each of six radial roads—or four lanes on one and two lanes on four other roads, a suitable width of roadway would be between limits of 24 and 36 ft.; due regard must be given to the volume of traffic in selecting the width.

Investigations made under working conditions, with calculations and estimates, are tabulated in the Report of the Ministry of War Transport, 1946, as shown on p. 102.

The roadway adjacent to the directional islands will usually be narrower, because a less density of traffic will be carried.

It is essential to allow for one or two (abreast) cyclists, and therefore a minimum width of 15 or 16 ft. is desirable; preferably it should be at least 22 ft.

Where, on circles of limited size, the outer kerb is concentric with the inner, and traffic is less than the capacity of the roundabout, the tendency will be to cut in or travel on the inside lane, so that the outer carriageway is little used.

1. Diameter of island (ft.).	2. Road width around island (ft).	3. Total width between outer kerbs (ft)	4. Maximum con-verging angle (degrees)	5 Peak capacity (vehicles per hour inc. cycles) up to ...	6. Remarks.
60	30	120	85	2,500	
75	30	135	59	3,000	
100	30	160	55	3,500	
105	40	185	59	4,000	Alternative layouts of which the larger island is to be preferred
150	30	210	40	4,000	
140	50	240	53	5,000	
180	40	260	40	5,000	
240	50	340	40	6,000	

Note.—The maximum volume in col. 5 should be used for an estimated future volume which should be 75% of the maximum capacity.

This condition may be avoided by straightening the outer kerb even though this causes a greater width of carriage-way than the minimum at the narrowest point. With large circles the trouble is less likely to occur, Fig. 63.

An example of a "split" traffic island is shown in Fig. 64.

Level of Centre Island.

A bold kerb, preferably with sloped face, should define the circumference of the circle; double kerbs are even better. It is good practice to not raise the soil, turf, or shrub more than about 3 ft. 6 in. above road level. This prevents dazzle from opposing traffic, but allows visibility for all drivers across the circle itself. With very large circles this question is not so important.

Direction Signs.

Ample direction and reflector signs should be placed on the radial roads and the island to assist traffic; the usual warning and approach signs are essential.

White lines are not usually necessary on the carriage-way either around the circle or at the entrances or exits.

Superelevation on Circles.

The crossfall to be provided to the road surface of a roundabout is an important feature for assisting the movement of traffic.

With small circles it is essential that the maximum safe banking should be given; in the case of larger roundabouts ample supereleva-

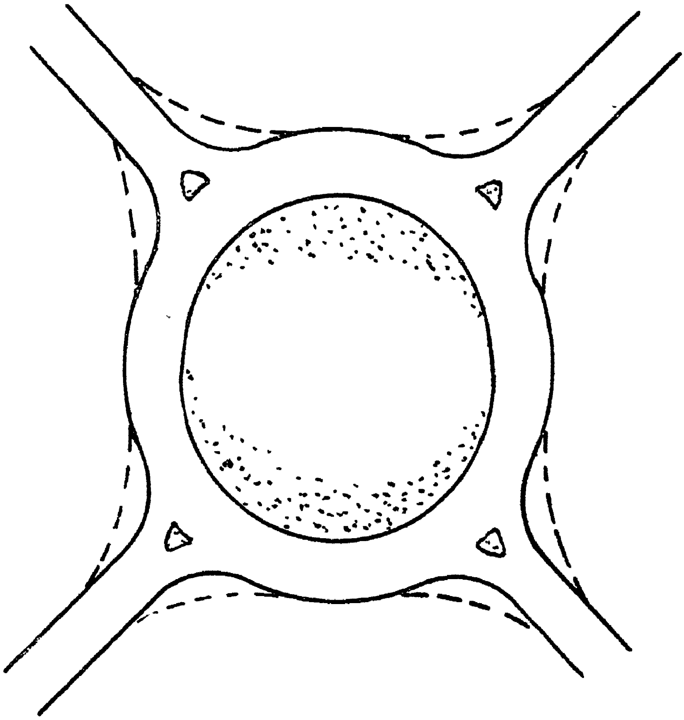


FIG. 63.—TRAFFIC CIRCLE SHOWING STRAIGHTENING OF OUTER KERB.

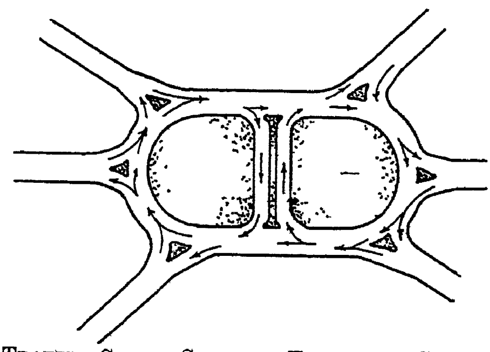


FIG. 64.—TRAFFIC CIRCLE SHOWING ELLIPTICAL CIRCLE AND SPLIT ISLAND.

tion should be provided. A useful guide is to make the inward banking for two-thirds of the road width and the outward slope for the remaining one-third; one is negative against the other positive, and care is therefore needed to avoid an abrupt change of road level

for "weaving" traffic; if the angle of "weave" is small there will be no discomfort or danger to steering.

Superelevation should be calculated for the design speed and the radius of curvature. The maximum crossfall should not exceed 1 in 10. Care should be taken to ease the change of the cross slopes at the crown by rounding off if necessary.

It is suggested that the difference between the inner and outer slope at the crown line should not exceed 5% for high design speeds, or 9% for slower speeds and shorter "weaving" distances.

The main object in designing curves, widths, and superelevation,

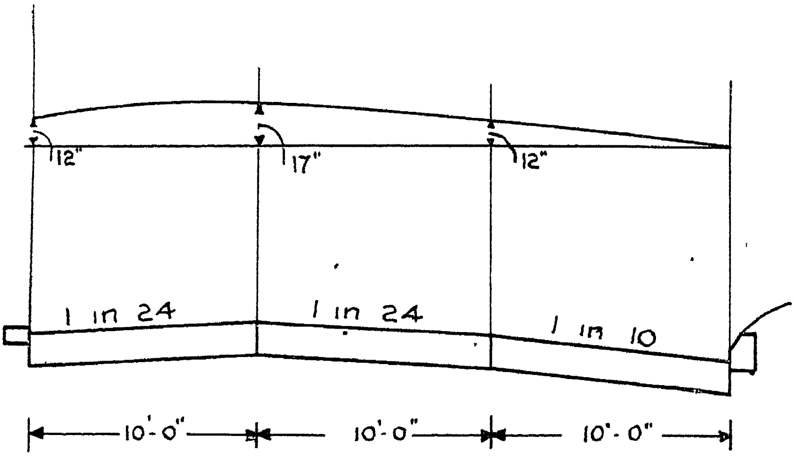


FIG. 65.—CROSS SECTION OF 30 FT. CARRIAGEWAY SHOWING VARIABLE SUPERELEVATION IN CONCRETE OR TAR MACADAM.

in connection with traffic circles, is to avoid undue braking or slowing down at the approaches.

Banking of the roadway at directional islands will be all one way—i.e. sloping downwards from the island—in addition to this, compound or transitional curves will help traffic to make the turn. An example of the banking and approach treatment is shown in Fig. 65.

Concrete paving lends itself to providing accurate crossfalls. With 10-ft. strips of concrete, a 30-ft. carriage-way may be banked with two different gradients inwards, and with one outwards. This minimizes the "roll" when weaving. In tar macadam the same result could be obtained by a parabolic curve; it should be noted that tar macadam or asphalte surfaces require special care to secure the correct finished levels.

Entrances and Exits.

These will vary with the existing conditions; an important consideration is that the design should ensure vehicles entering the circle

cautiously and slowly. Leaving the circle at speed is both safe and desirable. Entering traffic may be controlled in several ways :—

(*a*) By a "Halt" sign at some of the lesser-trafficked radial roads

(*b*) By "Stop" and "Go" signals suitably timed to prevent congestion on the circle, so that any traffic hold-up occurs on the radial roads. These signals will assist the passage of pedestrians.

(*c*) By well-designed directional islands; these will serve as refuges for pedestrians.

(*d*) By designing the circle so that the radial or entering traffic lanes are tangential.

(*e*) By designing the lay-out so that most of the change of direction is made on entering, while the exit is made more or less tangentially. This kind of island has been described as a turbine type rotary; an example is shown in Fig. 66. This is a reproduction of an aerial photograph of Davyhulme Circle, at Urmston, near Manchester. It was completed in 1928, the dimensions being as follows: diameter of the circle, 200 ft.; width of the carriage-way around the circle, 40 ft.; width of the carriage-way at the directional islands, 30 ft.; area of the whole circle, including the footpaths, etc., $2\frac{1}{2}$ acres. There are certain errors and advantages in the design, the errors being :—

1. Turn leftwards to directional island from the main road (top) is unsatisfactory for traffic; the bend is insufficiently superelevated.
2. The road around the circle is insufficiently superelevated.
3. The footpaths across and around the circle are undesirable.

Some of the advantages of the design are :

1. The carriage-way at 40 ft. allows for parking in the outside lane.
2. A car park area is provided (left of the photograph).

Provision for Cyclists and Pedestrians.

It is essential that pedestrians should not cross the central island or walk on the carriage-way. Crossings at the junction of the radial roads with the circle should be provided.

Normally cyclists will be able to use the carriage-way where traffic is not too heavy; otherwise, subways for pedestrians and cyclists may be obtained by raising the level of the circle, where this

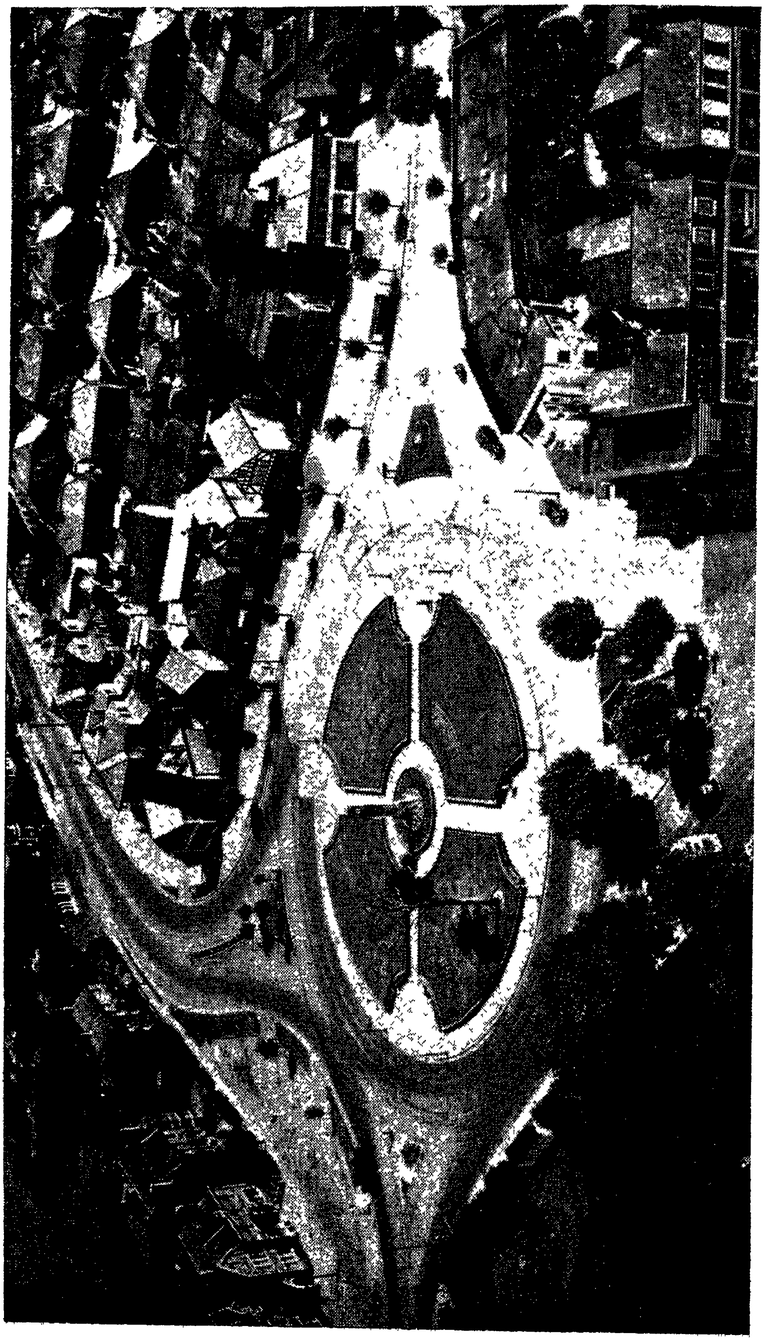


FIG. 66.—DAVYHULME CIRCLE, NR. MANCHESTER.

is practicable, up to about 10 ft : this will also avoid unwelcome gradients for these two classes of road-users.

It sometimes happens that circles are busy centres for pedestrians and it is necessary to provide some means of guiding them to the pedestrian crossings and preventing their straying and making short cuts on the carriage-way As an alternative to guard-rails for this

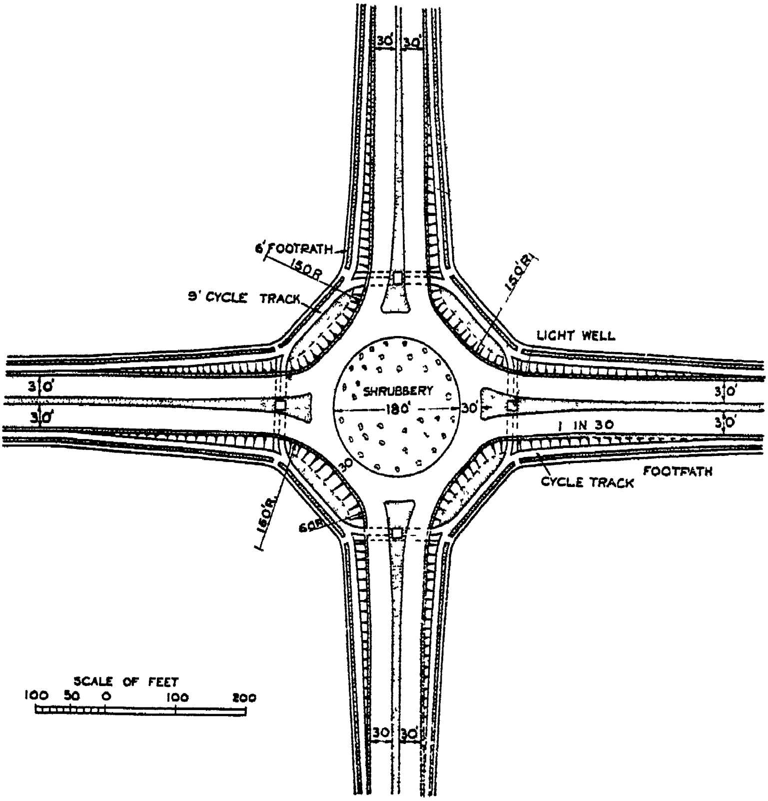


FIG 67 —DESIGN FOR TRAFFIC CIRCLE. (MIN OF TRANSPORT MEMO. No. 575)

purpose, a raised flower-bed, narrow according to the space available, and with attractive walling, will give a more pleasing appearance.

Two examples of circles which cater for cyclists and pedestrians are reproduced in Figs. 67 and 68 from the Ministry of Transport Memorandum No. 575. They show (Fig. 67) dual carriage-ways and cycle-tracks with separate circles; for preference the road circles should be raised to pass over the subways; and (Fig. 68) a roundabout at the same level with a special safety provision for cyclists entering the circle.

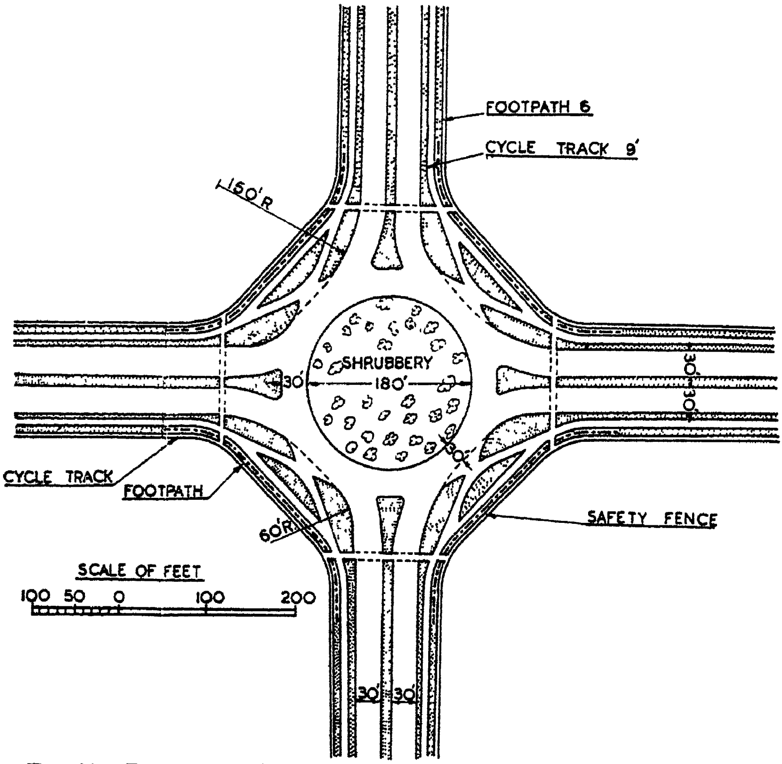
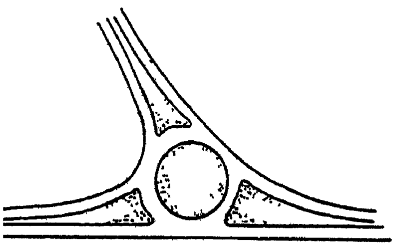
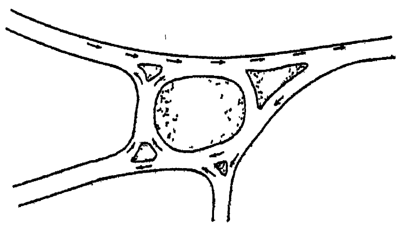


FIG. 68.—DESIGN FOR TRAFFIC CIRCLE. (MIN. OF TRANSPORT MEMO. No. 575.)



JUNCTION WITH ROTARY ISLAND.



JUNCTION WITH "TURBINE" TYPE ROTARY.

FIG. 69.—EXAMPLES IN AMERICAN PRACTICE IN TRAFFIC ISLANDS OR CIRCLES.

Fig. 69 shows examples of American practice in different types of traffic islands to serve the same purpose as circles.

An example of a circle carried out by the author is shown in Fig. 69*a*; this shows the contours and levels for superelevation.

MOTOR-WAYS AND GRADE SEPARATION

THE "Special Roads Act" was designed to simplify the procedure in embarking on the construction of motor-ways or express highways; it is expected that in due course work will begin on one or more of these roads as conditions permit.

A glance at the map of Britain and the motor-ways projected in the Ministry of Transport plan (Fig. 70) shows that the new roads will serve the densely populated areas of this comparatively small island.

The road from London to the north-west via the Midlands (Birmingham) and Lancashire, and then extending to Glasgow, would serve about 75% of the total population; naturally the motor-ways will pass close to or serve the large centres, like Birmingham, Manchester, and Liverpool; other roads, too, will serve the various ports.

The map shows also (in dotted line) the existing trunk routes which are to be improved to modern standards.

Design Standards.

Modern motor-ways are intended for relatively high-speed traffic—i.e. design spe[illegible] from 30 to 70 m.p.h.—grade separations or "fly-over" juncti[illegible] at limited intervals and dual carriage-ways are an essential fe[illegible] of this type of road. Where a road is not divided (as in links [illegible] existing highways) it is desirable that it should be separated by [illegible]ening at the approaches and through the intersection.

It will not b[illegible] appropriate to describe some examples of motor-way constructi[illegible] as carried out in U.S.A. and in Germany (up to 1939). Two examples of special interest in the former country are: (1) the Pennsylvania Turnpike Highway and (2) the Express Freeway at Houston (Texas).

The Pennsylvania Turnpike Highway.

The first section of this road connects Pittsburg with Harrisburg; the second section, constructed after the Second World War, extends the road from Harrisburg to Philadelphia. The first part is 160 miles long, with 7 miles of tunnels, 4¼ of which were built by the old South Pennsylvania railroad in 1885.

It is a concrete highway, with dual carriage-ways each 24 ft. wide

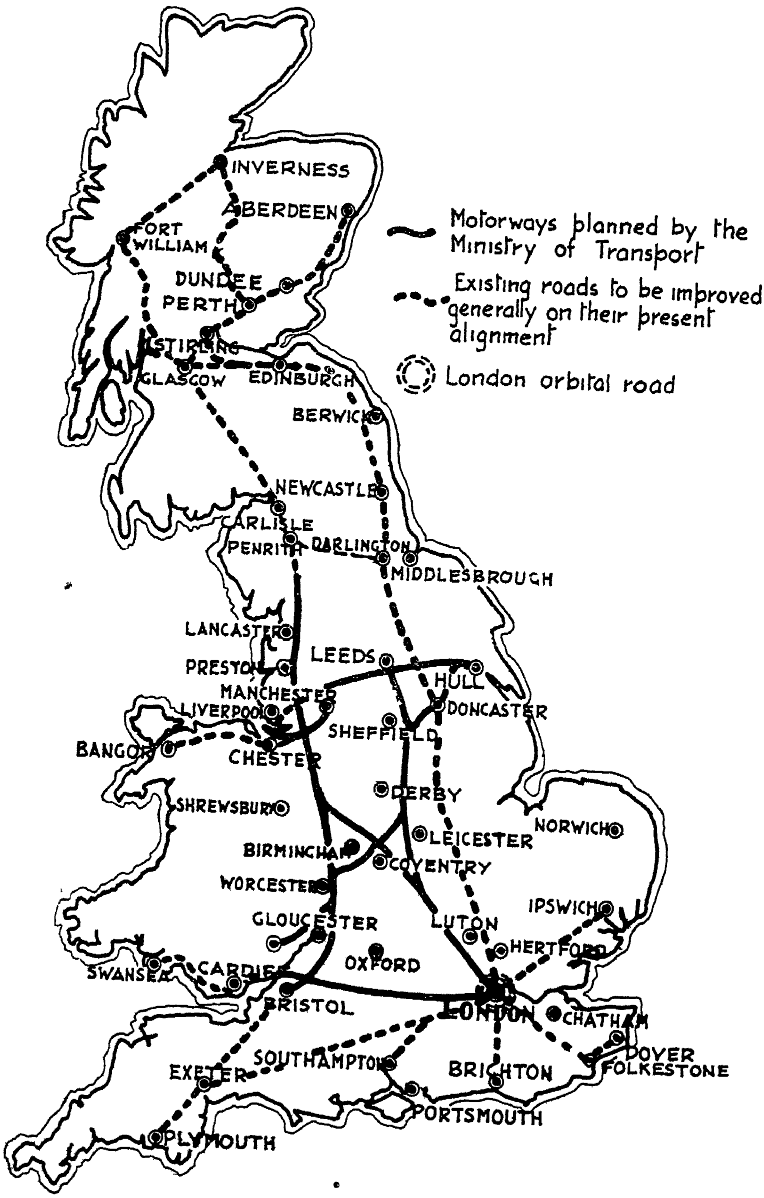


FIG. 70.—MAJOR SCHEMES OF ROAD DEVELOPMENT.

(except that in tunnels it is one 23-ft carriage-way with one lane each way).

The maximum up-grades do not exceed 3%, while curves, averaging about one per mile, are limited to about 4° with two only of 6°, i e a radius of 955 ft., which permits the maximum sight distance. It is free from any road or rail level-crossings, and toll-houses are built at each end and at ten points where there are grade intersections.

The road is located on the southern and western slopes of the Alleghenies, thus reducing maintenance costs, especially those due to snow and ice conditions.

The centre or median strip is about 10 ft. wide, and at night the fast traffic on the lane adjoining is guided by reflector dots mounted on thin rods at a height of about 3 ft. or eye-level. The maximum speed for car traffic which uses the outer lanes respectively is 70 m.p.h., while the heavy traffic uses the inner lane at the lower maximum speeds allowed.

It is expected that the tolls will ultimately pay for the road and its maintenance, and that it will then become the property of the State.

The Gulf Freeway at Houston (Texas).

This road, in concrete construction, provides for the efficient and safe movement of traffic within the city and between Houston and Galveston. The through section consists of six 12-ft. carriage-ways, three each way, with a 4-ft. centre strip. All intersecting streets and railways are over-passed; two (one-way) service roadways, 32 ft. wide, run parallel, and are separated by grass margins. The length is about 4 miles, and only limited access is allowed; the right-of-way costs amounted to about one-third of the cost of construction. At the city end there are four "feeder" streets with signal-controlled intersections at sixty-eight points. The speed limit on the Freeway is 45 m.p.h., and on the service and feeder roads 30 m.p.h. Parking in the city area has been met temporarily by street parking, garages, and parking sites.

It is estimated that the construction of this road has saved time on passenger and commercial vehicles which is valued at about £1,000,000 per annum.

The German Motor Roads (Autobahn).

(*a*) The majority of roads in this system, built pre-war, have two carriage-ways each about 28 ft. wide, with a centre strip varying from 16 to 28 ft. for different roads; footpaths, from 6 to 16 ft., are provided where required.

On straight lengths the crossfall is 1·5% to 2% towards the outer margin; on curves the degree of superelevation rarely exceeds 6%.

On hillsides the carriage-ways are laid at different levels, with slope centre strip, or on steep hills with a retaining wall between.

The edges of the centre strip and outer margin are metalled from 16 to 40 in., these extra strips are called "bankettes". Where possible 13-ft. outer strips of land were acquired for tree-planting; it was considered that three rows of trees in the centre strips would prevent "glare". Parking places are provided at points of special interest. Generally speaking, the landscape work has been most successful.

(b) *Sight Distance and Curves.* The horizontal and vertical curves are based on calculations of average braking distances assuming a coefficient of friction of 0·4–0·5 and allowing for drivers' reaction time.

The minimum radius, R, is about 1,150 ft; between this radius and about 1,800 ft. the transition curves are of the compound type, the larger radius being $2.R.$ (see Fig. 19*a*).

Vertical and horizontal curves were carefully designed to give ample sight-distance; the graph showing the relations between vertical curves, sight-distance, stopping space, is given in Fig. 36; braking distances were calculated for theoretical speeds up to 125 m.p h. on level sections and on 3% gradients.

A braking distance of 1,000 ft. on flat section is taken as the normal clear view; in some cases a distance of 650 ft. was adopted.

Most of the road surfaces were of two-course concrete paving, 8–10 in. thick, unreinforced and laid upon waterproof paper. The centre longitudinal joint was formed by an inset at the bottom, with a groove cut in the top of the slab after the initial set. Transverse joints of special bituminous filler were placed at intervals of about 60 ft.

Segmental sett paving was used in hilly districts and for all loop roads and acceleration lanes.

A variety of grade separations were used, including "trumpet" and other designs in vogue in America; examples of these are shown in Figs. 71 and 72.

It has been pointed out that some of the vertical and horizontal curves were not successfully co-ordinated; possibly this was done for reasons of economy. The system includes many bridges of concrete masonry and steel, a large number of which have a bold and pleasing appearance.

"*Fly-over*" *Junctions or Grade Separations.*

It is clear that for motor-ways, where two important busy roads, with relatively high-design speeds, intersect, it is desirable to carry one road over the other by bridging and connecting ramps. If it is not expedient to construct the "fly-over" immediately, provision

of land should be made so that it can be carried out at a later date; if this reservation is made, new fast roads can be laid out as dual carriage-ways, or one road, with the second one to come later; if

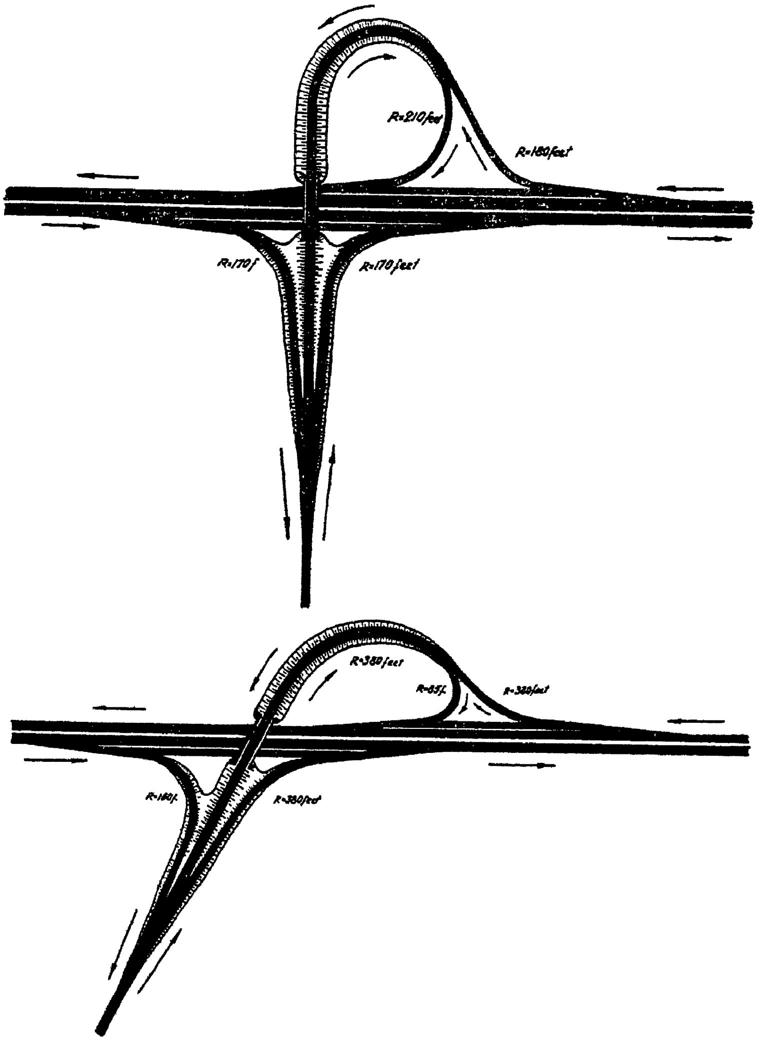


FIG. 71.—TYPES OF GRADE SEPARATIONS ON GERMAN AUTOBAHN.

need be, traffic circles could be introduced as a temporary measure.

Grade separations (as they are known in the United States, where they are quite common practice) are necessary for the following reasons :—

(a) To assist the rapid and uninterrupted movement of large volumes of traffic.

(b) To remove bottle-necks and peak-period congestion.
(c) To create road-safety conditions for high-speed traffic.
(d) They are useful in hilly country, where a grade intersection fits the topography better than surface junction.

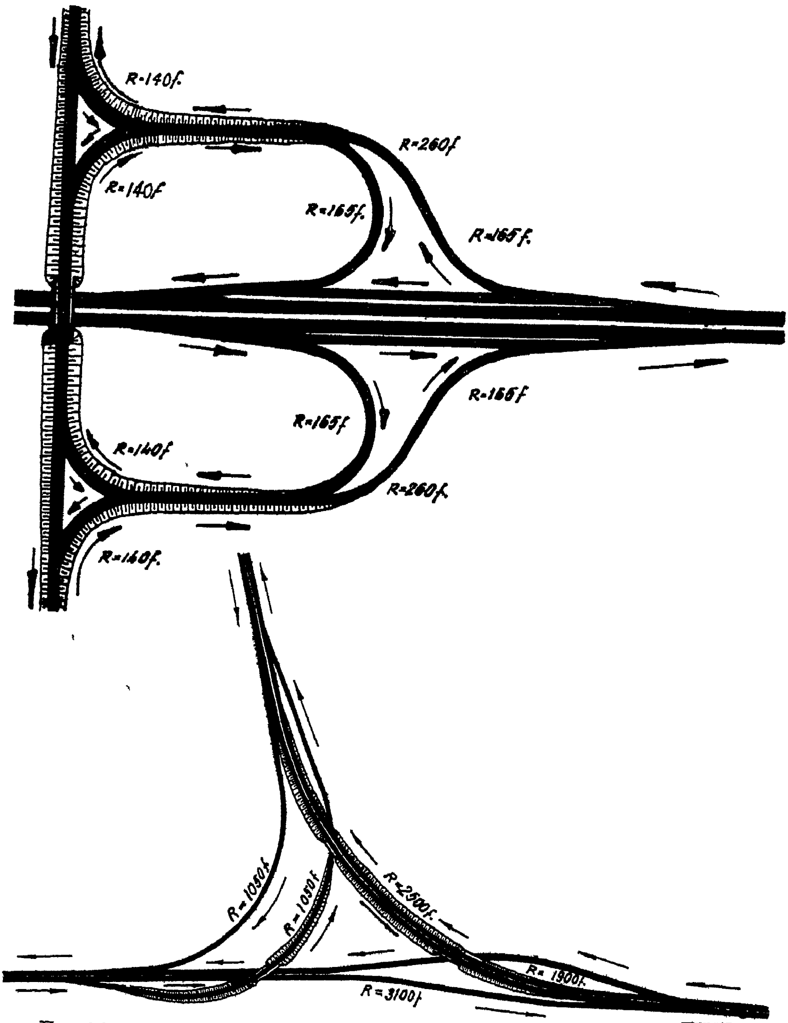


FIG. 72.—TYPES OF GRADE SEPARATIONS ON GERMAN AUTOBAHN.

Naturally grade separations, whether over or under, are costly, and a careful analysis of traffic, present and future, should be made in the first instance, and the whole related to the less costly type of intersections at the same level.

There are many points to consider in connection with the design of these junctions, and a brief summary of recommendations of the American Association of State Highway Officials is given below.

Grades, Alignment, and Sight Distance. The sight distance must be equal to the standard for the highway, and should not be reduced by gradients or poor alignment, these standards are not easy to attain. Where there is mixed traffic, gradients at the approaches to the intersection should not exceed 1 in 20.

Clearances at Structure. Barrier kerbs should be located 3 ft. outside the normal edge of the pavement; bridge rails, abutment walls, or piers to support a high-level footpath should be 3 ft beyond the barrier kerbs.

Continuous kerbs on the approaches or auxiliary lanes should provide clearance beyond the edge of the pavement of 4 to 6 ft.

Undivided Highways. Four-lane roads should be divided at grade separations with ramps; two-lane and three-lane roads should be widened to four-lane, if at all possible; if not, then a two-lane road should be widened to 3 ft. through the intersection.

The centre strip should be at least 4 ft., and the alignment curvature should be 1° or less.

Centre piers should allow for kerbs with 4-ft. clearance.

Ramps at Clover-leafs. Left exit and left entrance turns should be either on the major roads or on those which best assist traffic to leave both the through roads.

Ramp Curvature. Ramps should enable vehicles to leave the major road at 70% of the design speed, and transition or compound curves should be used; if curves are too sharp, acceleration or deceleration lanes should be used. Reverse curves are undesirable; widths of ramps should be similar to that of the lanes at surface junctions.

Ramp Gradients. These should be limited to 4–6% (1 in 25 to 1 in 17); one-way ramp gradients may be up to 1 in 12½; there should be flat gradients at the terminal connections with the through roads.

Ramp Profiles. For two-lane ramps the rate of change of superelevation should not exceed 0·06–0·08 per 100 ft.; superelevation on one-way down-grades may be steeper.

In landscape treatment slopes should be not steeper than 1 in 2½, to assist maintenance.

Control Devices. Ramps and approaches should have lanes marked with white lines; arrows and "Stop" lines are effective at terminals.

Where a widening lane is provided, the surface should be of a contrasting colour.

Ample signs are necessary.

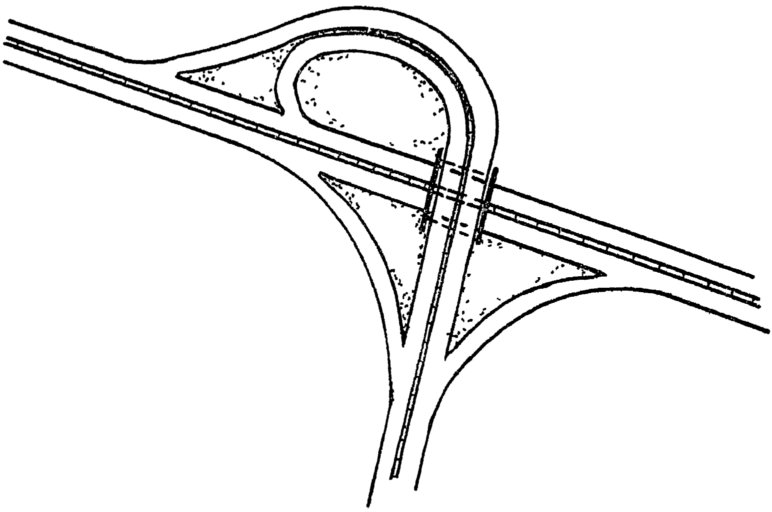


Fig. 73(a).—"Trumpet" Type of Grade Intersection (U.S. Practice).

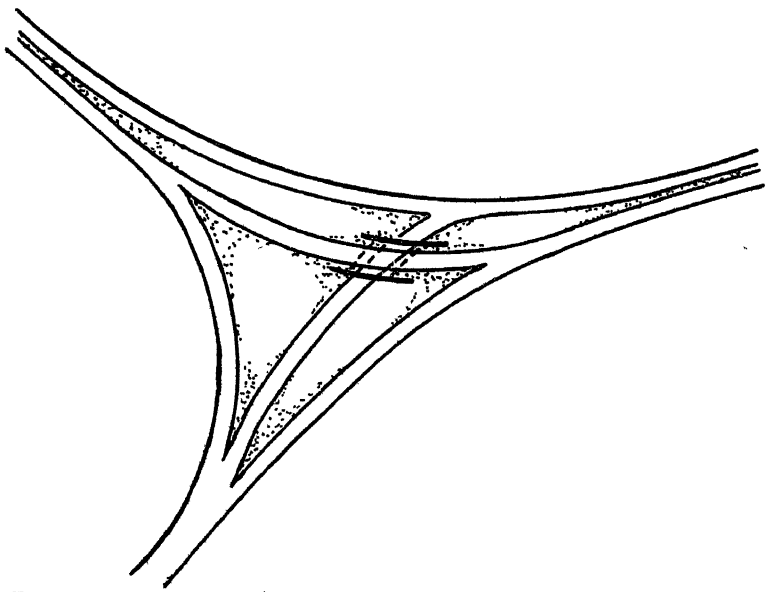


Fig. 73(b).—Simple Type of Grade Intersection (Y Intersection) (U.S. Practice).

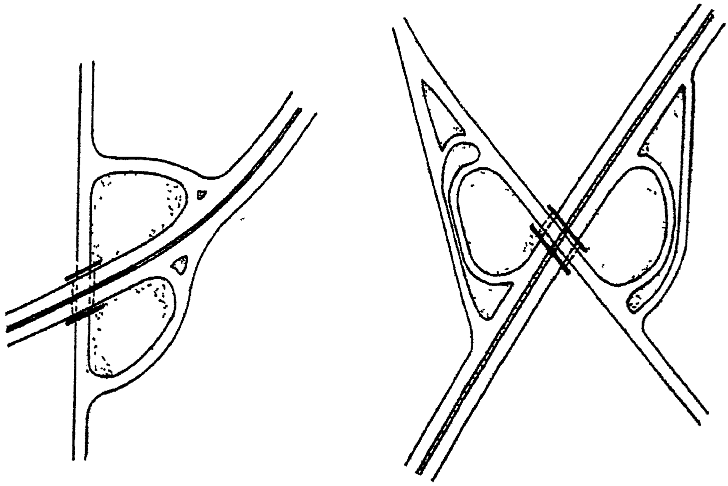


FIG. 73(c).—2 RAMP TYPE GRADE SEPARATION (U.S. PRACTICE).

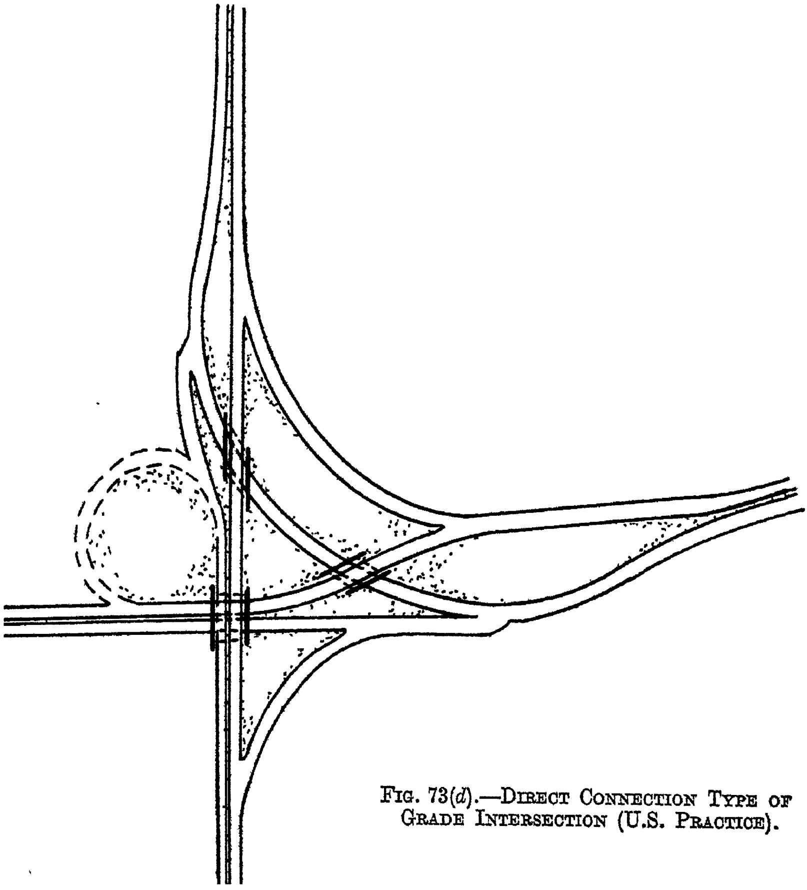


FIG. 73(d).—DIRECT CONNECTION TYPE OF GRADE INTERSECTION (U.S. PRACTICE).

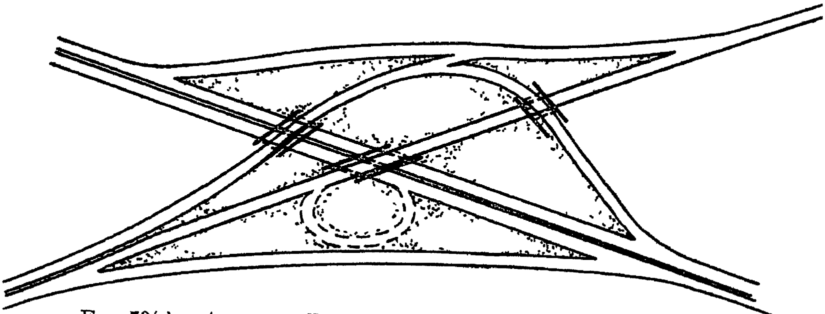


FIG. 73(*e*).—ANOTHER EXAMPLE OF DIRECT CONNECTION DESIGN IN GRADE INTERSECTION (U.S PRACTICE).

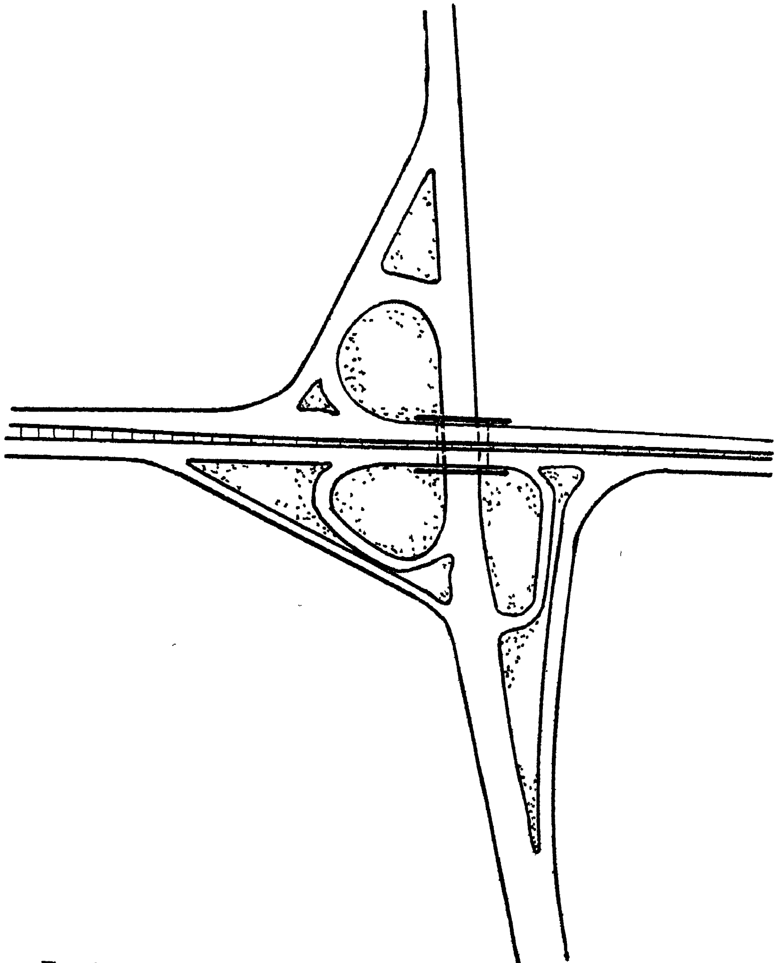


FIG. 74(*a*).—TYPES OF GRADE SEPARATION (U.S. PRACTICE). 3 RAMP CLOVER-LEAF PATTERN, SIMPLIFIED.

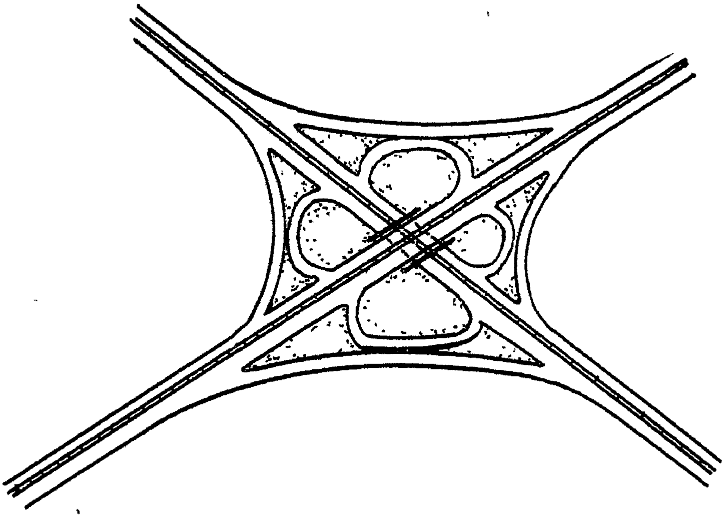


FIG. 74(b) —4 RAMP CLOVER-LEAF INTERSECTION (U.S. DESIGN).

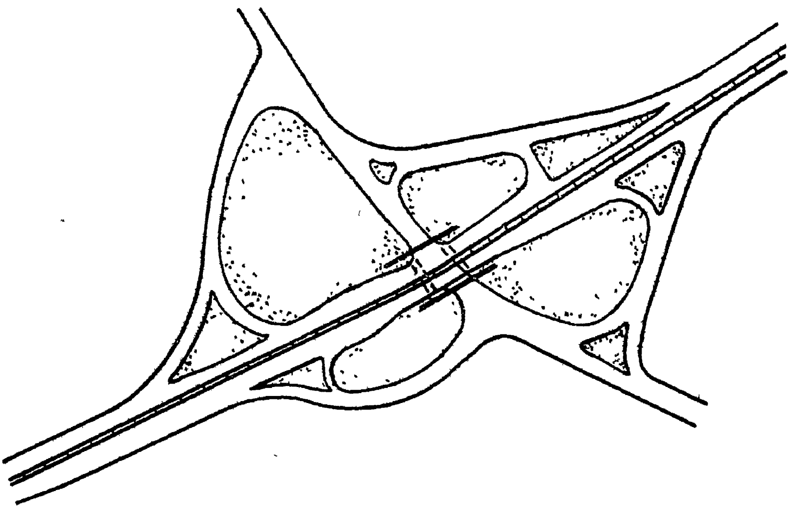


FIG. 74(c).—4 RAMP GRADE INTERSECTION (U.S. DESIGN).

Pedestrians. Footpath space on one side of each intersecting road should be provided; paths on ramps should be to the best natural line and gradient.

Lighting. At intersections with ramps for turning movements, fixed lighting is helpful.

There are many designs of grade intersections which can be applied according to topographical conditions and requirements. These

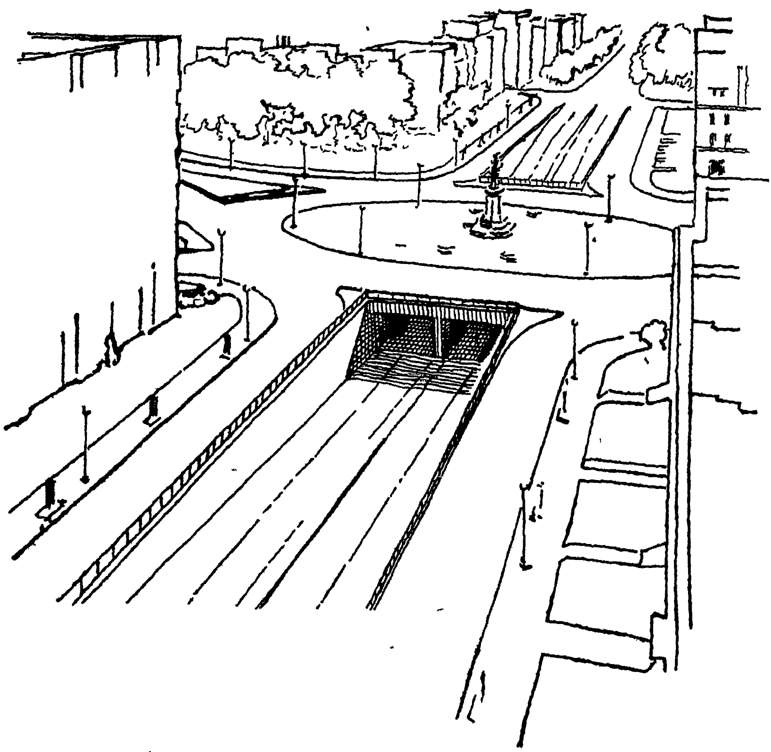


FIG. 75.—SCOTT CIRCLE (WASHINGTON, D.C. UNDER-PASS).

include under-pass and over-pass; two-ramp, three-ramp, and four-ramp (clover-leaf) intersections; trumpet type and Y intersections and "direct-connection" designs; they are shown diagrammatically in Figs. 73 and 74.

Traffic Circle Under-pass Design.

The high cost of the ramp designs and the large area of land required lead to consideration of less expensive construction. One type which is easy to plan is that of a trunk road passing beneath a traffic circle; generally two bridges are required, and if practicable

the circle may be raised; in any case, drainage of an under-pass road may present problems for the economic and effective disposal of storm-water.

The Scott circle at Washington (Fig. 75) is an excellent example of this type of construction, the under-pass road being built long after the initial building of the circle.

Headroom for Under-pass Roads.

One advantage which American design has, as against that prevailing in this country, is in the height of bridges over roads; they have a minimum height of 14 ft., whereas the Ministry of Transport here specifies 16 ft. 6 in.; the latter height requires longer gradients or ramps, and therefore necessitates more costly construction.

CHANNELIZING FOR TRAFFIC

WHEN Mr. T H Macdonald (Chief of the U.S. Bureau of Public Roads) was asked by the Author "What is the most important road development in America since World War II?" he replied succinctly, "Channelization"!

This section deals with some of the methods now adopted to ensure a high degree of safety at road junctions; the main object is to guide traffic safely from one road to or across another, and to give space for halting, if need be, to allow the main road traffic to pass before entering or crossing.

One-way Systems.

The movement of traffic is greatly facilitated by the establishment of the one-way street system. This system has now become so very widely adopted that a brief mention only is necessary.

Narrow streets, wherever possible, should be converted for one-way traffic, as this will obviously prevent congestion and will often allow for limited parking without interference with through traffic. A one-way road will carry a greater number of vehicles per hour than the same road used for two-way traffic, because of the delay caused by standing vehicles. The point of entry should be determined with a view to maintaining the best continuous or rotary flow to carry the greatest volume of traffic. Adjacent one-way streets carrying traffic in opposite directions are a very desirable method of linking up two busy main roads.

Ample signs for day and night direction should be provided at all intersections, and especially "Look Left" and "Look Right" signs as warnings to pedestrians. These should be prominently marked on the surface of the road or footway.

In some crowded districts, unimportant, short streets have been completely closed to traffic in the interests of safety for children; in such cases adequate warning signs should be provided.

Traffic Lanes.

White or yellow lines have been widely adopted, and have proved exceedingly useful on curves, cross-road intersections, T-junctions, bridges and approaches, steep hills, level crossings, and road-narrowings. The presence of these lines should divide the opposing

lanes of traffic into their respective zones and warn them to proceed without overtaking.

The memorandum of the Ministry of Transport recommends that on classified roads each lane should be 11 ft. on a two-lane road; for more than two lanes the width should be 10 ft.

The marking lines (in white plastic) should be 4–5 in. wide, and generally they will be a 3-ft. mark with a 15-ft. gap; on the four-lane road the centre line will have a 13-ft. mark and a 3-ft. gap.

Continuous centre lines starting at 100 ft. from the tangent points will be used on curves with a sight distance of less than 1,000 ft.; the three-lane markings should terminate 200 ft from the tangent points.

Where the line of the kerb or verge is broken by a road junction it should be continued by an intermittent line with 3-ft. marks and 3-ft. gaps. On single carriage-way roads a solid white centre line should be used where visibility distance is below the standard for safety, having regard to the speed value for the road.

Tidal Traffic.

On busy wide roads leading to cities or popular resorts traffic tends to be "tidal", i.e. the traffic going one way is several times greater than that going in the opposite direction. Later in the day the reverse is the case for the homeward journey. For example, on a four-lane highway without centre strip three lanes could run one way and one lane the other way. To control this may be difficult without careful consideration for the whole length of the road; it should be mentioned here that a method is in use in America in which kerb lines are raised mechanically to regulate the one lane against the several lanes in the opposite direction as required. When the conditions warrant the change in the opposite direction or an equal flow, this kerb is lowered to the level of the carriage-way; the kerb is then raised similarly on the opposite side to accommodate the homeward-bound traffic in the several lanes in the opposite direction.

Design of Islands—the "Traffic Prow."

Islands should be well defined, with suitable kerbs levelled or hollowed to assist in deflecting the wheels of any vehicle colliding with the island.

For the sharp point of the island it is a good plan to design a "prow" which will act as an easy check should a vehicle collide with the island in a fog, for instance. A detail of the island designed by Dr. McClintoch (of Harvard) is shown in Fig. 76.

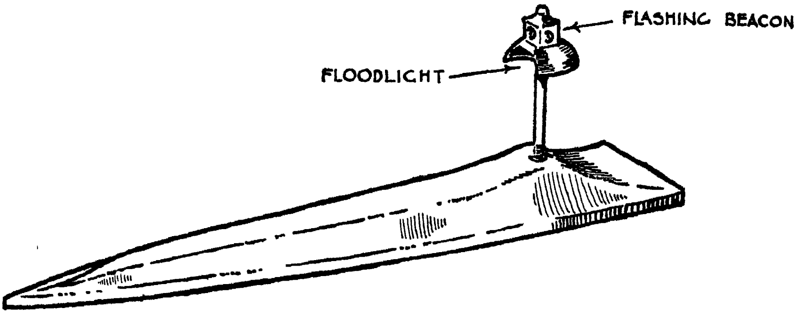


FIG. 76.—McCLINTOCK TRAFFIC PROW.

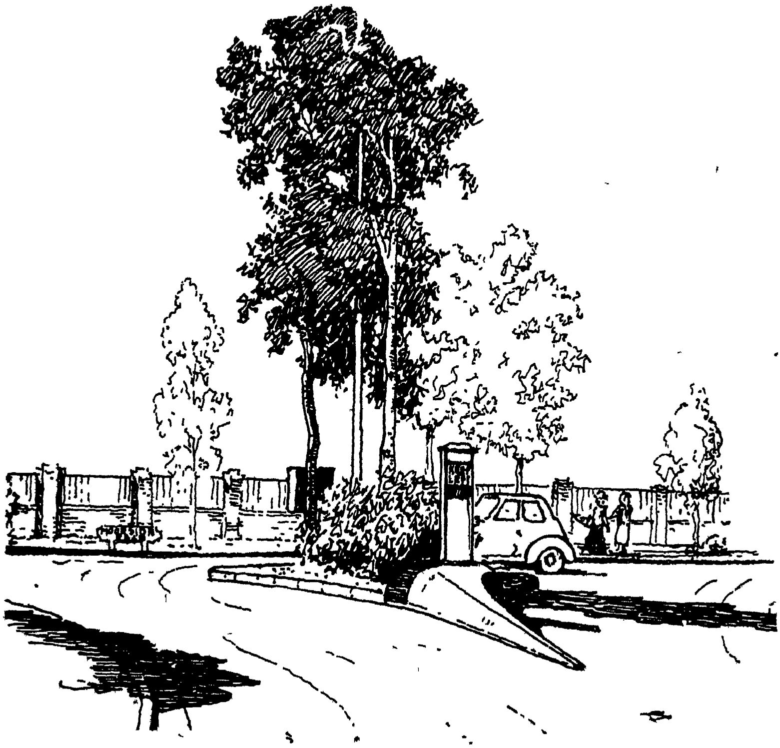


FIG. 77.—TRAFFIC PROW (URMSTON, LANCS.).

Another design adopted in Urmston and somewhat similar is shown in Fig. 77. If a vehicle hits the side of the prow with one wheel it is deflected; if it meets it "head-on" the front axle will slide up the sloping ridge and so brought to a stop gradually and therefore with reasonable safety.

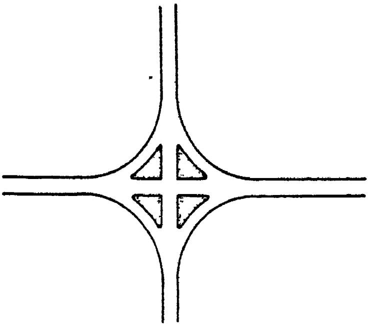


FIG. 78.—SQUARE INTERSECTIONS.

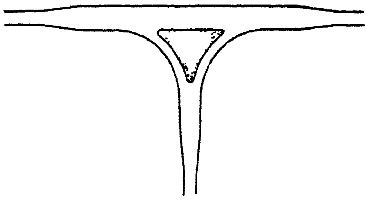


FIG. 79.—T JUNCTION (WITH SEPARATE TURNING LANES).

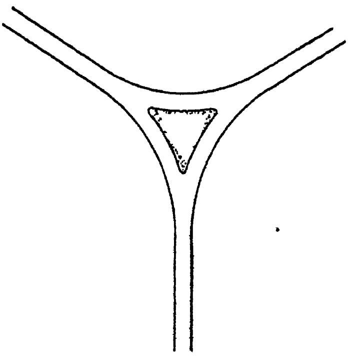


FIG. 80(*a*).—Y JUNCTION ON EQUILATERAL.

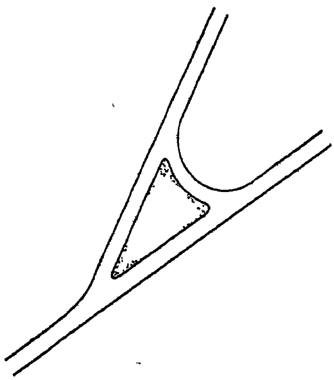


FIG. 80(*b*).—SIMPLE TYPE Y JUNCTION.

Flaring.

It will be found advantageous to widen the carriage-ways at the approaches to junctions; this enables an additional lane to be provided for acceleration, deceleration, or weaving by turning traffic. In some cases it may be possible to have a different colour to the surface of one of the lanes as a further guide to traffic.

A number of examples are given here of methods of channelizing for the various types of road intersections.

1. *Square Intersection.* In Fig. 78 four branch roads provide for traffic to make an easy left turn from one road to the other; the

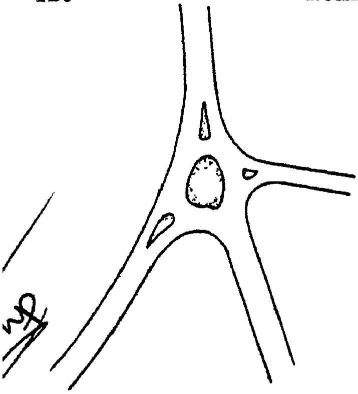


FIG. 80(c).—SIMPLE TYPE OF Y JUNCTION WITH ROTARY ISLAND.

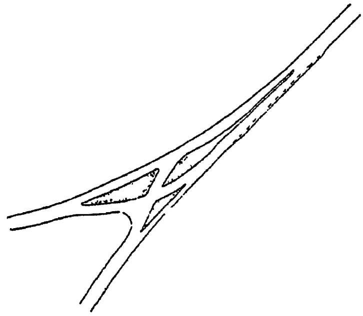


FIG. 81.—CHANNELIZED Y JUNCTION WITH RESTING SECTIONS FOR TRAFFIC.

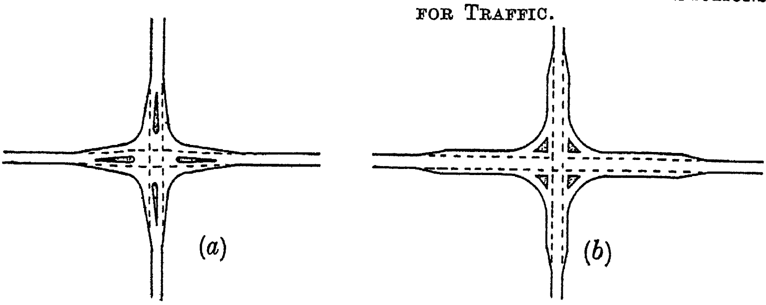


FIG. 82.—"FLARING" AND SEPARATING ISLANDS.

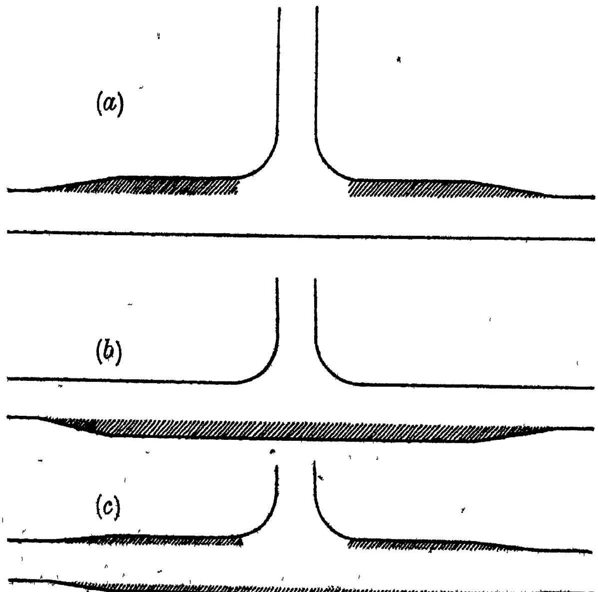


FIG. 83.—METHODS OF FLARING AT T JUNCTION.

immediate cross-over can be controlled by "halt" signs or signals, or, less efficiently, by "slow" signs, "flaring" may be introduced if required.

2. T *Junction.* This shows right and left curves for easy movement of two-way traffic (Fig. 79): the width of roadway on the curves should be at least 24 ft.

Flaring of the main road is of great assistance to traffic joining or leaving the main road.

3. Y *Junctions.* Three examples (Figs. 80*a-c*) are shown for connections for types of Y junction by the use of large islands.

4. *Channelized* Y *Junction.* This method shows (Fig. 81) how directional islands may be employed to create short one-way roads which allow resting space at the one point where there is across-over.

5. *Flared Intersections.* Examples are shown in Figs. 82 and 83 of "flaring" and separating islands; Fig. 82*a* for an intersection of a

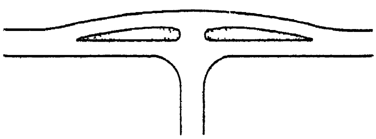


FIG. 84.—DIVIDING ISLANDS FOR T JUNCTION.

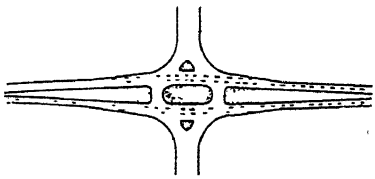


FIG. 85.—WAITING SPACE FOR VEHICLES ON DUAL-CARRIAGEWAYS.

major and minor road; and Fig. 82*b* for an intersection of two major roads.

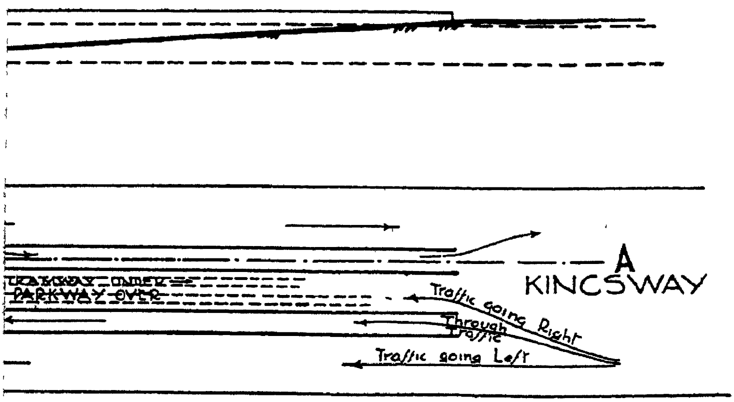
6. *Methods of Flaring at* T *Junction.* There are three methods of widening or "flaring" at a T Junction, viz. (*a*) by widening on the same side as the branch road; (*b*) by widening on the opposite side; and (*c*) by widening equally on both sides of the main road to give an extra lane; these are shown in Fig. 83.

7. *Dividing Islands for* T *Junction.* These may be provided by widening sufficiently to form tapered central islands; in Fig. 84 it is suggested that the island should be in colour and be raised slightly, somewhat on the lines of a modified traffic prow.

8. *Waiting Space on Dual Carriage-ways.* On a dual carriage-way road the centre island may be no wider than 4 ft. and frequently is not greater than 10 ft. This does not allow waiting space for traffic making a right turn either from the main road or from a branch road; by widening out the two carriage-ways as shown in Fig. 85, a separate island may be formed with "Turn Left" signs facing the minor roads; this will allow waiting space for traffic making the cross-over.

The principles of grade separation may be applied at any inter-

section where there is sufficient space to allow for the connecting roads and ramps. An example of simple grade-separation is the passage of the tramway beneath the crossing at Holborn and the Strand in the Kingsway, London. If a ramp were provided in the south side of Holborn, a considerable traffic relief would be felt at this point. This suggestion is illustrated in Fig. 86. When trams are discontinued, it should not be difficult to widen the subway a little on the south side of the Holborn crossing, and so enable an up-and-down ramp to be constructed while leaving the centre—i.e. the present subway—free for through traffic to and from the Embankment.



A
KINGSWAY
TRAMWAY UNDER
PARKWAY OVER
Traffic going Right
Through Traffic
Traffic going Left

[To face p. 128.

CHAPTER XII

SETT-PAVED ROADS

The demands of heavy mechanical traffic and also of horse-drawn vehicles in past years brought about the adoption of sett or block paving.

The types of block paving in existence in this country may be classified as follows :—

(a) Grit-sett paving.
(b) Granite-sett paving.
(c) Wood-block paving.

(a) Grit-sett Paving

As a general rule, grit setts are laid on a non-rigid surface, the reason for this being that the base of the paving must offer a cushioning effect for the setts when subjected to impact of wheel loads. This fact renders it impossible to maintain a smooth surface for any length of time, and, in addition, there is a likelihood of potholes developing, due to a splitting of the setts themselves. It is not difficult to keep a grit-sett road in a good state of repair for lighter traffic, so long as the defects are dealt with in the early stages.

Method of Raising Setts for Repair of Potholes.

Where one sett has subsided, it may be raised by means of a simple device which the author has used. This consists of two rods about 12 in. long, with a ring at one end and the other tapered and formed like a fish-hook, as shown in Fig. 87, so that it may be driven down at the opposite corners of the sett, below the base, and turned, and then lifted by the leverage of crowbars. The foundation having been restored, a new block may now be rammed and grouted into position. As an alternative to this, concrete may be used to replace the defective sett or setts, thus obtaining a tight joint with the adjoining paving. It would be necessary, however, to keep traffic off the surface for several days in order to give time for the concrete to harden. Grit setts will be found useful for really hilly work and in localities where the stone is at hand. The grouting of this kind of paving requires special care, as it is difficult to keep out water when laid upon a non-rigid foundation. It is usual to fill the joints by brushing in chippings prior to grouting with a suitable mixture of pitch grout.

(b) Granite Setts

This kind of paving is decidedly more suited to modern conditions than grit setts, granite being much better able to resist impact blows from traffic, whether on a rigid or non-rigid surface. The setts may be of various shapes, generally either rectangular or cube-shaped. In the past, when non-rigid foundations were the rule rather than the exception, deep setts were often used in order to strengthen the

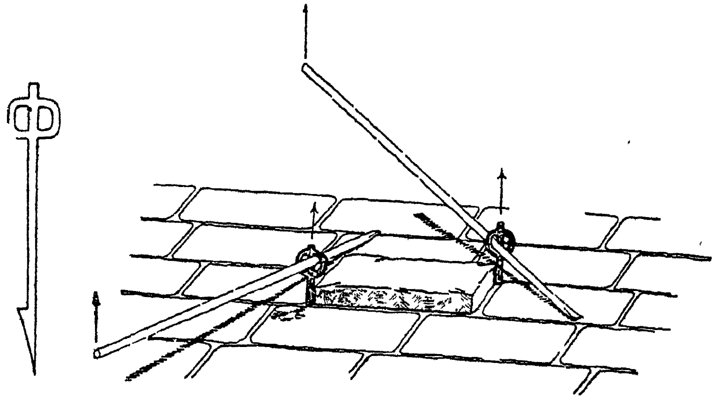


Fig. 87.—Lift Hook for Raising Setts.

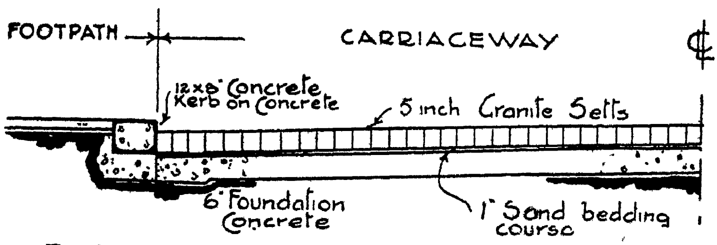


Fig. 88.—Granite Cube Setts on Concrete Foundation.

pavement and at the same time provide against wear for a long term of years. The later tendency, however, was to lay new paving upon a concrete foundation, and it was then unnecessary to adopt setts deeper than about 5 in. Fig. 88 shows cubes paved on a ½-in. to 1-in. bedding course of sand and on a concrete foundation. The cost of this kind of paving is greater than that of bituminous surfaces, and therefore sett paving is going out of fashion.

(c) Wood-block Paving

Wood blocks impregnated with creosote form a durable, smooth, and noiseless road material. This kind of pavement is usually to

be found in cities, where noiseless conditions are required. Wood blocks are often considered suitable for bridges, owing to their lightness and resilient qualities; a medium or soft-wood paving will give the most satisfactory results. The timber most generally used is obtained from Sweden, Archangel, and Finland. It should be heavy, close-grained, of uniform texture and susceptible to impregnation by creosote. The quantity absorbed should be between 8 and 10 lb. per cu. ft. of timber.

Other tests and standards required include the oil content, water absorption, shearing strength impact, expansion, and shrinkage.

Method of Laying Wood Blocks.

Wood blocks should be laid on the smooth surface of a concrete foundation, the depth of which should not be less than 6 in. of 6 : 1 composition, where not reinforced, and on good average subgrade, as shown in Fig. 89.

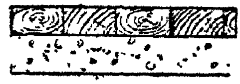


FIG. 89.—WOOD BLOCK PAVING.

On no account should the blocks be laid on a bedding course, as this assists in causing an uneven surface, especially when the jointing material softens in hot weather. The blocks may be dipped in a hot soft pitch composition prior to paving, or be laid dry. The joints in each case should be filled up with pitch, close to the surface, and the remainder filled with cement-sand: it is usual to provide an expansion joint alongside the kerb.

Preservation of Wood-block Paving.

The treatment for the preservation of wood-block paving should be effected, where necessary, by cleaning the joints and flushing with hot coal-tar of specific gravity of about 1·20 at the rate of about 1 gal. per sq. yd., which should be swept in with brushes or squeegees. An application of sand is necessary to prevent the wheels of traffic lifting the tar. Under certain weather conditions wood-block paving tends to become slippery and gritting may become necessary.

Diagonal Paving.

The usual method of laying setts at intersecting roads is that of diagonal paving to form a gusset. This is done in the interests of horse-traffic, but it has a further value, in that it presents a lower tractive resistance and wears better than the straight or transverse joints. In the case of wood-block paving a diagonal arrangement of the blocks forms an attractive carriage-way, as shown in Fig. 90.

Segmental Paving.

Segmental paving has been used with varying success; it provides a diagonal paving, but it offers also certain weak points at the intersection of the segments. The setts which are small are paved to form segments or arches in plan, of a span of about 5 ft. Where the

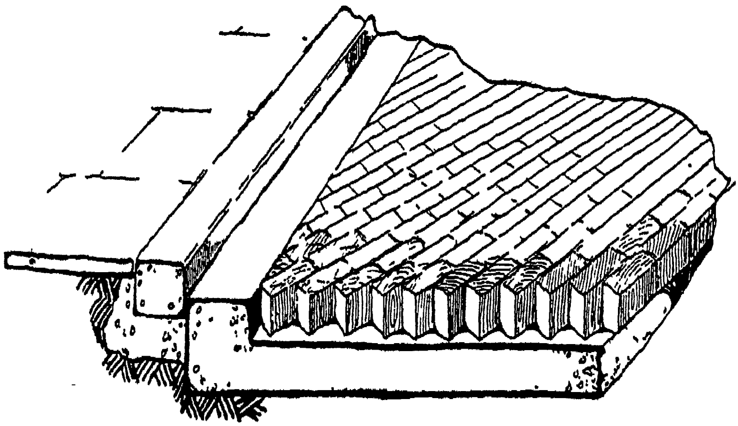


FIG. 90.—DIAGONAL PAVING.

segments touch or spring from each other it is not easy to mitre the blocks, and generally it is at these points that potholes or waves begin.

Obsolete Tramways.

This form of transport is rapidly being superseded by the motor omnibus; the usual practice is to leave the rails in the road and to arrange for a two-course layer of bituminous macadam to be laid over the existing road; this involves raising kerbs, footways, and manhole covers. The result is a modern satisfactory carriage-way with a good foundation, produced at low cost. With suitable lifting plant it is possible to tear up tram-rails at an economic cost.

CHAPTER XIV

BITUMINOUS, TARRED, AND RUBBER ROADS

In dealing with the question of bitumen or tar macadam roads, it is desirable to examine briefly the characteristics of bitumen in its application to all kinds of road surfacing work.

Occurrence of Bitumen.

The term bitumen is often applied in a comprehensive way to include in some degree coal tar. Geographically, bitumen is widely distributed over the globe (*a*) as natural gas; (*b*) in liquid form as petroleum; and (*c*) in heavier form as native solid bitumen in Venezuela, Cuba, Trinidad, Mexico, and the Middle East.

Chemically bitumen belongs to a group of hydrocarbons which include some sulphur, oxygen, and nitrogen, all soluble in CS_2. Oil residual bitumens are derived from industrial distillation of petroleum.

Natural rock asphalte was discovered in the early part of the seventeenth century in Neuchatel in Switzerland; it consists of limestone impregnated with bitumen. There are other deposits in Sicily, France, Trinidad, and the United States.

The Trinidad pitch lake has a maximum depth of solid bitumen of about 135 ft., and is estimated to contain 9,000,000 tons of bitumen. The material, as dug from the lake, has the following average composition :—

Volatile at 212° F.	29%
Bitumen soluble in CS_2	39%
Mineral matter (ash)	27·5%
Organic matter, insoluble	4·5%
	100%

When refined at 325° F. it has the following composition and properties :—

Bitumen soluble in CS_2	56·5%
Mineral matter (ash)	38·5%
Organic matter, insoluble	5·0%
	100%
Specific gravity at 60° F.	1·40
Softening point	180° F.
Flowing point	235° F.
Penetration at 77° F.	4°

An oil medium is added for softening, with the following properties :—

Specific gravity	0·92
Flash point . .	350°

After about two hours' agitation of bitumen-and-oil mixture the analysis is as follows :—

Bitumen soluble in CS_2 .	67 0%
Mineral matter (ash) . .	28 5%
Organic matter, insoluble . .	4 5%
	100%
Specific gravity	1 27
Penetration at 77° F .	60°

Before proceeding to deal with the different types of bituminous roads, it is proposed to give the principal physical and chemical tests applied to bitumen.

Tests for Bituminous Material

It will be possible only to give below a brief description of tests which are carried out on bituminous materials.

1. *Specific Gravity.*

This is really a volume test against weight; to check the specific gravity the following formula should be used :—

$$V = \frac{1}{S}$$

where V = vol. in galls. at 60° F.,
S = specific gravity at 60° F

2. *Melting Point.*

Two methods may be used here: (*a*) the cube method; and (*b*) the ring-and-ball method.

In the former method (*a*) the cube of the material is moulded to 0·5 in. cube and attached to a wire. The cube is placed in the inner beaker (Fig. 94), which is heated at a rate of 9° F. per minute.

The temperature at which the material touches a piece of paper in the bottom of the beaker is taken as the melting point.

In the ring-and-ball test the material is moulded into a brass ring ⅝ in. diameter, and ¾ in. deep. A steel ball ⅜ in. diameter, weighing 3·50 grams, is placed in the centre of the ring and suspended in a beaker and heated as in Fig. 95. The softening point is the temperature at which the specimen drops 1 in.

3. *Flash Point.*

This is the temperature at which vapours are given off the heated material (in special cups) and which flash temporarily when contacted by a small flame, it is important in relation to fire risk.

4. *Solubility.*

This is determined by the percentage of the sample that will dissolve in carbon disulphide or some other solvent. There are

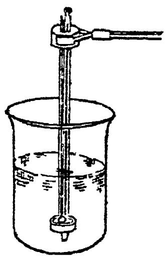


FIG. 95.—MELTING-POINT APPARATUS FOR RING-AND-BALL TEST.

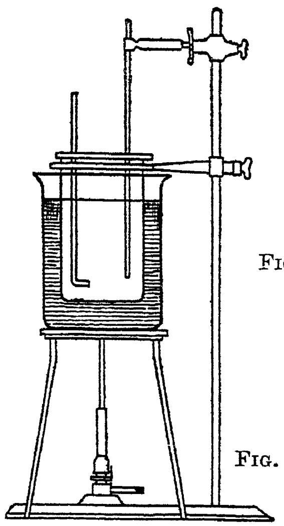


FIG. 94.—MELTING-POINT APPARATUS FOR CUBE METHOD.

several methods whereby this test on asphalte-paving mixtures is made, of which only brief mention may be made here :—

(a) *Funnel Method.* The sample (up to 500 grams) is dissolved through a filter-paper and 8-in.-diameter funnel by trichloroethylene.
(b) *Hot Extractor Method.* The weighed sample and the solvent is heated in a cylinder lined with gauze
(c) *Centrifuge Method.* Dissolved bitumen washed from the sample by carbon tetrachloride is decanted into 7-in.-diameter centrifuge tubes; these are balanced and centrifuged from five minutes at 4,000 r.p.m. tq separate the mineral matters.
(d) *Methylene-chloride Method.* A metal cylindrical extraction vessel revolved at 60 r.p.m. is used, and the solution is filtered under pressure by inserting a porous aluminium thimble with appropriate connections.

(e) *Pressure-filter Method.* This is similar to (d), but the steel cylinder is revolved at 50–60 r p.m for a longer period.

(f) *Rebstein-extractor Method.* The apparatus employed is a tinned copper-coil condenser with funnel, paper extractor, and conical flask.

(g) *Soxhlet-extractor Method.* A filter thimble with a Soxhlet extractor centrifuged for ten minutes at 1,500 r.p.m.

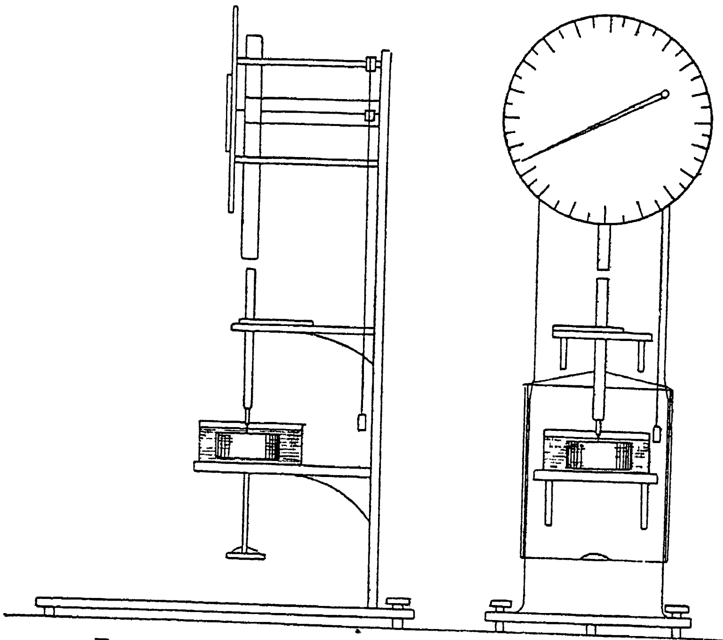


FIG. 96.—PENETROMETER FOR PENETRATION TEST.

Fixed Carbon.

This is determined by heating in a closed platinum crucible 1 gram of bitumen until all smoke-volatile products have been driven off and only ash remains.

The difference between initial and final weight is the fixed carbon value.

Penetration—Field or Plant Test.

The penetration test is the distance measured in units that a standard blunt needle will penetrate a sample of asphalte (in water at 77° F.), the needle being loaded with 100 grams and applied for five seconds.

In the laboratory a penetrometer (Fig. 96) is used, the penetration

being measured in $\frac{1}{100}$ centimetre; the softer the asphalte the greater is the penetration.

Viscosity.

This is measured by the time required for a given amount of material to flow through a tube of standard dimensions into a measuring flask.

Two types of "viscometer" are used: the "Saybolt-Furol" and the "Engler". In the former the viscosity is the time in seconds required for 60 c.c. of material to flow through the small diameter orifice, in the latter, where the head of oil is less, it is the time taken for 50 c.c to flow through the orifice.

The test temperature should always be stated; the specific viscosity is related to the time of flow of water through the same orifice.

The "Float" test is also used to measure viscosity (Fig. 97), the apparatus being an aluminium float or saucer, and a small threaded collar which is filled with the material to be tested; it is floated in the water-bath at the specified temperature—e g. 90° F. or 122° F.—until the bituminous material softens and allows the water to break through. The time taken is noted; this test is useful for materials too soft for the penetration test

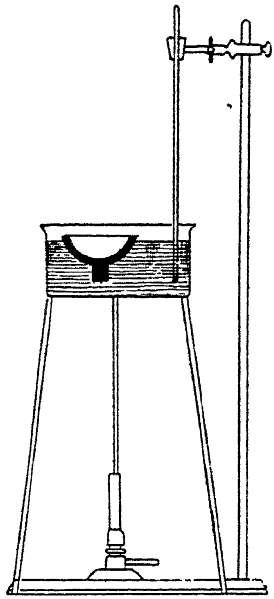


FIG 97.—FLOAT TEST FOR VISCOSITY.

Ductility.

This test consists of moulding a briquette of bituminous material 3 cm. × 1 cm. × 2 cm. and stretching it (in water, at 77° F.) at a specified rate of pull until it breaks; the pull is usually 5 cm. per minute. The power is applied by means of a worm-gear pulling from right to left.

The distance registered (in cm.) at the time of rupture is the ductility of the bitumen.

Coefficient of Expansion.

Fluid bitumen is poured into a calibrated dilatometer, which is heated in an oven; the coefficient may be found from the following formula:—

$$K = \frac{V^1 - V}{V(t^1 - t)}$$

where V and V^1 are the volumes at the normal and observed temperatures t and t^1.

An alternative method of specific-gravity comparisons is useful for semi-solid bitumen; the above formula with specific gravity substituted in place of volumes will apply.

Impact Tests.

These are made on an Impact machine with briquettes, 2 in. diameter by 1 in. high; a 2-kg. weight falls through 4 cm., 6 cm., then 10, 18, 34, and 66 cm., respectively; the number of blows to produce failure is noted.

Other tests which may be undertaken include oven loss, distillation, and the Oliensis Spot Test.

ASPHALTE SURFACINGS

There are three types of asphaltic roads :—

1. Rock asphalte.
2. Mastic asphalte.
3. Rolled asphalte.

1. *Rock asphalte* consists "naturally" of fine limestone impregnated with bitumen up to about 12%; it is prepared to a specification of 11% bitumen, 68% limestone passing No. 200 B.S. sieve and 21% between $\frac{1}{8}$-in. to 200 B.S. sieve. It is heated and mixed on site to 300–350° F., and laid to a thickness of $1\frac{1}{2}$ to 2 in. on a rigid foundation.

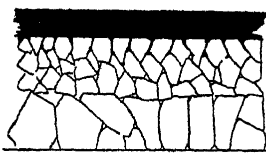


FIG. 98.—ASPHALTE WEARING COURSE ON EXISTING MACADAM ROAD WITH BINDER COURSE.

Generally the success of an asphalte pavement depends on the retention of its elastic and cushioning properties; when ultimate compression is reached the pavement tends to disintegrate.

2. *Mastic Asphalte.* This is a prepared asphalte made into blocks which are broken and re-heated with 40% of $\frac{3}{8}$–$\frac{1}{8}$-in. granite chippings; the limestone is about 22%, $\frac{1}{8}$ to No. 200, and $29\frac{1}{2}$% passing No. 200 B.S. sieve; bitumen $= 8\frac{1}{2}$%; it is laid about $1\frac{1}{2}$ in. thick with wooden floats; an example of a $1\frac{1}{2}$ in. asphalte course on a binder course is shown in Fig. 98.

This specification produces a strong wearing surface; $\frac{3}{4}$ in. precoated chippings give a non-skid surface.

3. *Rolled Asphalte.* This is used and rolled hot from spreading

machines, and can be laid up to several hundred tons per day; the aggregate of sand (⅛ in. to No. 200) and/or chippings may be varied for a bitumen content, between 7½ and 10%; the content would decrease as the percentage of chippings increased.

Surfacing is laid with ¾-in. pre-coated chippings, total thickness about 2 in. With a coarser aggregate the mix may be described as a bituminous concrete.

The table below shows some average gradings for bituminous concrete mixtures —

Average grading of bituminous concrete.	Mixtures.		
	1.	2.	3.
Passing 100-mesh sieve	6 3%	8·0%	8·8%
„ 80-mesh sieve	1·2%	1·0%	0·8%
„ 60-mesh sieve	2 5%	3·2%	3·2%
„ 40-mesh sieve	7·0%	6·1%	5·8%
„ 20-mesh sieve	8·0%	13·0%	12·3%
„ 10-mesh sieve	4·9%	10 2%	8·0%
„ 8-mesh sieve	1 3%	3 8%	2·8%
„ 4-mesh sieve	9·5%	17·0%	14·5%
„ ½-in. screen	26·3%	19·2%	25·2%
„ ¾-in. screen	18·7%	13·7%	17·6%
„ 1-in. screen	12·8%	5·0%	0·0%
„ 1¼ in. screen	0·3%	6·0%	0·0%
Specific gravity of stone	2·93	2·97	2 86
„ „ sand	2 70	2·70	2·63
Percentage of voids in aggregate	21·98	20·76	21·39
„ bitumen soluble in CS_2	6·90	7·35	6·80

Clinker Asphalte.

In this case the aggregate consists of crushed and screened destructor clinker, ½ in. for the bottom course (bitumen 10%) and ⅛ in. and down-grade (bitumen 17%) for the wearing course; it is mixed on the site and laid hot, rolling being with about a 12-ton roller.

Reinforced Bituminous Concrete.

Experiments carried out in the East Riding of Yorkshire showed that by placing reinforcement fabric at 4–5 in. deep in a bituminous macadam, the surface remained in an excellent condition long after the unreinforced section had failed.

Rubber Paving

Numerous experimental lengths of rubber-block paving have been laid from time to time, with varying success.

Two of the types used are: (*a*) the "Cowper" block, 9 in. × 4½ in.

$\times$ $2\frac{1}{2}$ in. deep, tongued and grooved; and (*b*) the "Cresson" block, 9 in $\times$ 3 in. $\times$ $3\frac{1}{2}$ in. deep, composed of a hard base made of chippings, sand and rubber latex, compressed and vulcanized with a $\frac{3}{8}$-in. resilient top.

Other blocks of varying design have been tried out to a limited extent, but the high initial cost has prevented any serious development, having regard to the efficiency and economy of other types of road surfaces.

Rubberized Asphalte.

Experimental lengths of road have been laid, in Britain and elsewhere, with asphaltic pavements containing a small percentage of fine rubber; it is contended that the rubber imparts a greater resilience to the asphalte, partly due to the swollen particles of rubber and partly to some of the rubber being absorbed into the bitumen solution.

It will take time to establish the true value of this mixture, but all such experiments will be watched with great interest.

Cold Bituminous Emulsions

This method of road-making has become increasingly popular, mainly owing to the convenience of using a cold emulsion which is not seriously affected by damp conditions; it includes surface dressing, grouting, retread, pre-mix, soil stabilization, concrete curing, and tack coats. These emulsions are liquid mixtures of residual asphaltic oils or semi-solid asphaltic residues, water, and a small proportion of an emulsifying agent.

The asphalte is dispersed as fine globules in the water or vice versa; they are classed broadly as "quick breaking", "slow breaking", or "semi-stable".

The former is used for surface treatment, penetration, etc.; the latter do not break rapidly, and are therefore adapted to mixing operations. The physical properties embrace dispersion, viscosity, stability in storage, and breaking characteristics in use; the tests for consistency include viscosity, float, and penetration, and the volatility tests, flash point, oven loss, and distillation; field tests will include washing test, settlement test, and residue tests.

The emulsions are varied according to requirements; they may be soapy solution, colloidal clay, or proteins such as casein or glue—the latter being suitable for stable mixtures.

Breaking Point.

This is produced by evaporation, coagulation, or porosity; loss of water may occur by using fine aggregate or cement.

Double-surface Treatment

Good results are obtained by applying a liquid bitumen of low viscosity, and after drying out applying a heavier bitumen with a coating of one size chippings, using a box spreader.

A second application with fine chippings will fill in the surface voids of the first coat.

One application with chippings constitutes "single-surface treatment".

Seal coats with bitumen and fine chips may be applied some time afterwards, making the third application, by this means a thickness of from 1 to 1½ in. is obtained, according to the size of the chippings used in the first application.

The following table gives the rates for this treatment :—

Rates.	Application.			Ultimate thickness.
	First.	Second.	Third.	
Gauge .	½–¾ in.	⅛–⅜ in.	—	½ in.
Per ton .	120 sq. yd.	150 sq. yd.		
Per gallon .	4–8 sq. yd.	4 sq. yd.		
Gauge .	¾–1 in.	¼–⅜ in.	⅛–¼ in.	1 in.
Per ton .	30–40 sq. yd.	150–180 sq. yd.	180 sq. yd.	
Per gallon	4–8 sq. yd.	3 sq. yd.	4 sq. yd.	
Gauge .	¾–1½ in.	¼–⅜ in.	⅛–¼ in.	1½ in.
Per ton .	20–30 sq. yd.	150–180 sq. yd.	180 sq. yd.	
Per gallon .	4–8 sq. yd.	2½ sq. yd.	4 sq. yd.	

Re-treading.

Re-treading is the term used for re-shaping an existing road-crust of up to 6 in. depth by scarifying and by the use of bituminous emulsion as the binder—this "mix-in-place" method is economical.

The existing surface is scarified to a depth of about 2½–3 in., then broken up and re-distributed by harrowing and mixing; hot tar may be used instead of cold emulsion.

The plant required comprises an 8–10-ton roller with scarifier attached or drawn, harrows or cultivators, blade-grader, tractor, pressure distributor, and gritting lorries.

The scarified aggregate is levelled out to the desired shape by the drawn weighted cultivators, and new material is added where required to fill depressions; re-shaping to the contour is done by the blade-grader and rolling; great care should be exercised to obtain a true shape; for emulsions the aggregate should have a suitable moisture content.

Grouting is then carried out by the pressure distributor at the rate of about ½ gal. per sq. yd. with cold emulsion (two applications are

required), or ¾ gal in the case of hot tar. The cultivator should be drawn through the material where emulsion is used; this is to be followed by rolling

Tar-spraying and chipping may be carried out a few days afterwards with advantage.

Re-treading for Light Traffic Roads.

There are many country roads which carry only light traffic and which consist of not more than 4–6 in. of water-bound macadam

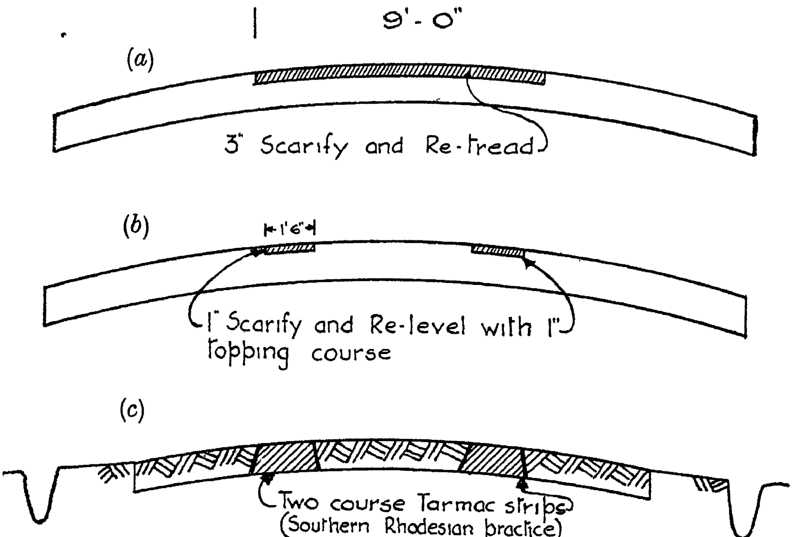


FIG. 100.—DIAGRAM SHOWING METHOD OF RE-TREADING LIGHT TRAFFIC ROAD AT LOW COST.

tar-sprayed; many Class III roads are of this type of construction, and the road widths may be from 15 to 18 ft. In such cases traffic holds to the crown of the road, and waviness of track wear soon develops.

There are two ways in which improvement may be effected at low cost: (*a*) by scarifying the centre or crown to a width of about 8 or 9 ft and re-treading (Fig. 100*a*); or (*b*) by scarifying the two wheel-tracks each to a width of about 18 in. and about 1 in. deep and re-levelling with a topping course of tar macadam (Fig. 100*b*). This treatment is similar to the "strip" tarmac roads used in Southern Rhodesia (Fig. 100*c*).

In the case of the strip roads, it may be necessary to scarify to a depth of 2½–3 in. and to insert about 2 in. of tarmac base course

before laying the wearing course: it is essential that the latter should be of an even thickness Surface dressing and rolling over the whole surface may be carried out afterwards as required.

B.S. Specifications on Tar Macadam.

The preparation of tar macadam is covered by the following British Standard Specifications :—

1. No 802/45 : deals with all types of tar macadam and tar carpets manufactured with granite, limestone, or slag.
2. No. 1241/45 : deals with all types of tar macadam and tar carpets manufactured with gravel aggregate.
3. No. 1242/45 : deals with all types of tar paving for light traffic using natural aggregate or slag.

These specifications are a guide to the quality and suitability of the materials.

Plant Inspection.

To ensure good work, it is important for manufacturing plant to be inspected where large quantities are involved.

All bituminous material aggregates and fillers must be tested before use. This should include frequent laboratory tests; storage and segregation of material; weighing devices; cleanliness; thermometer and temperature recordings; mixing operations; moisture content for cold asphalte mixes; checking mixture by dissolving bitumen and analysing the aggregate by screening. All these points and many others of a more general nature are important if one desires to get the best results in road paving and if the B.S. Specifications are to be followed.

In tar spraying work it is important to check for the even distribution of the jets of the tank sprayer; this is done by filling separate trays for each jet.

Penetration Macadam.

This method involves the use of clean, dry aggregate laid and rolled to a depth of about 3 in. to receive the hot or cold bituminous treatment and $\frac{1}{2}$–$\frac{3}{4}$-in. chippings; rolling should then be carried out as in other treatments. The procedure may be carried out by one heavy application or two or three lighter applications, with chippings and rollings in each case.

Rolling—General.

Rolling should begin at the sides and work towards the centre; wheel-marks should be overlapped and rolled out and any depressions

corrected. All creases and marks must be rolled out, and rolling carried on until the surface does not creep or push under the wheels.

Rollers, preferably of the tandem type, should be equipped with water-spray and scrapers on wheels; three-wheel rollers may be used after the mixture is cooled.

Rolling diagonally and at right angles is advantageous if width of road is sufficient for the purpose.

Joints.

At the end of a day's work the transverse joint should be rolled off and the following day a vertical joint is made by cutting back and painting same with a hot or cold bitumen; the fresh mixture is then rolled against the vertical face.

SURFACE DRESSING

With Cold Emulsion.

As in all cases of surface dressing, the surface must be clean, and swept if necessary to remove dirt and dust; potholes should be cut out diamond shape, and filled with 1½-in. to ½-in. graded aggregate, treated with cold emulsion, and chipped and rolled or punned.

Emulsion may now be applied either from the drums with cans or by pressure distributor. Brooms or squeegees are useful for distributing the emulsion—the rate will vary from 3 to 6 sq. yd. to the gallon, according to conditions and size of chippings to be used; the latter should be from ⅜ to ½ in. gauge (consisting of granite, limestone, slag, or local stone), and be evenly spread and then rolled. If possible, traffic should be kept off the dressed surface until the emulsion has set.

Tack Coat.

This is usually applied to clean, hard, impervious surfaces as a prime coat prior to laying a carpet coat. If applied by distribution, the speed of application may need to be fast, in order to give only a light coat of about 0·10–0·15 gallon per square yard. Uniformity may be obtained by drawing a burlap behind the distributor. The surface must be kept tacky or sticky until the carpet is laid.

Surface Dressing on Burned and Planed Surfaces.

It often happens that previous tar dressings develop a corrugated surface, so that a further surface dressing would be futile. In some cases the macadam base also may show signs of corrugation or disturbance.

If burning apparatus with controlled burner is used for the purpose of softening only, then a rotary planer will remove the ridges and level off the surface shape to the required camber.

The restored surface may well be sufficiently stable to carry traffic for some considerable time, a surface dressing, however, may be applied at any time afterwards with good results, and after a limited period a second dressing may be given with advantage. As always, the results are better if traffic is kept off the dressed surface for some hours and if, moreover, the work is not hampered by wet weather.

The advantages of the method are (*a*) economy, (*b*) smoothness of running, and (*c*) a well-prepared surface for subsequent tar treatment and chipping.

CHAPTER XV

CONCRETE ROADS

THE destructive effect of heavy mechanical traffic on the majority of existing roads in this country has brought about the construction of the paving surface itself in Portland cement concrete.

It will be shown elsewhere that surface inequalities of roads are due to the movement of the surface material itself, to a greater or lesser extent, and if no movement is possible, either horizontal or vertical, then wave formation is practically eliminated In considering the advisability of adopting concrete for main roads, this point should be fully understood. The main difference between concrete and the other road formations lies in the binder, which, being of cement, forms in combination with the other constituents of concrete an absolutely rigid mass.

One of the first concrete roads built in this country was laid at Saltney in the city of Chester in 1912 (in Ohio, U.S A., the first concrete pavement was laid in 1893).

From that time until recently the development of the concrete pavement has proceeded steadily, and a considerably increased mileage of this class of road is being laid down annually, despite post-war restrictions.

The points which should occur to the engineer in the selection of concrete as a paving material are as follows :—

1. *Initial Cost.*

The cost of laying a concrete slab is very little more than in laying a concrete foundation. *There is less excavation,* and in many cases a strong existing foundation is available, and may permit a reduction in the thickness of the slab. The cost will compare very favourably indeed with other materials when these are laid upon a concrete foundation.

It is not enough to compare merely the initial cost of a road; the cost of maintenance, its public utility, and wearing qualities must also be considered.

2. *Cleanliness.*

The concrete road is a very sanitary pavement, on account of its smooth hard surface, which is practically self-cleansing, and in the absence of tar-surface treatment the concrete does not produce

detritus or other material to be washed off in rainy weather, as is the case with some types of surface. This smoothness also permits of a flatter camber or cross-fall only.

3. *Noiselessness.*

A well-laid concrete road is reasonably noiseless under all kinds of traffic, and with a hard-wearing surface this quality will be maintained over a period of several years.

4 *Tractive Resistance.*

The low tractive resistance of concrete paving means a minimum vibration of traffic, also the rear-axle vibration is practically eliminated, since this occurs only when the surface is uneven.

Up to the present, experience indicates that the cost of maintenance of concrete road surfaces is very low.

The cost has decreased with the decline of horse traffic and other iron-tyred vehicles and with the increase of pneumatic-rubber tyres.

The disadvantages of concrete as a road surface which present themselves at the moment are as follows :—

1. *Reinstatement.*

The difficulty of reinstatement after any disturbance of the road has taken place is alluded to elsewhere. Concrete roads can be repaired, however, by careful design and by using rapid-hardening cement.

2. *Gradients.*

On steep gradients concrete will be ruled out as undesirable, its smooth surface affording an insufficient grip for horse-traffic. It should be noted, however, that the application of tar or bitumen and chippings will increase the tractive resistance, and thus temporarily supply this deficiency. Cement-bound macadam has been used with success on hills, since it presents a non-skid surface.

3. *Warping.*

This occurs because of surface expansion due to variation in moisture and temperature between the top and the base of the slab, this causes a certain waviness or warping, which may be counteracted by the insertion of warping joints in the upper part of the slab.

Treatment of Foundations.

The success of the concrete road is not a little due to proper treatment of the subgrade and foundation of the road. Where the

subsoil is waterlogged, drains and cross-trenches should be laid to pass away the water which would otherwise remain under the slab. Where the natural drainage conditions and the subsoil are good no special provision need be made.

Generally speaking, a new foundation bed is improved in its bearing qualities by a layer of 2 or 3 in. of cinders, gravel, sand, or broken stone, which, also, will assist in keeping the top surface of the subsoil drained. Where concrete is being substituted for existing road material the matter of foundation is comparatively simple, although it may be necessary to provide subsoil drainage where soft ground is suspected.

Materials.

The whole secret of success of the concrete road centres round the care bestowed upon the selection, proportioning, mixing, and laying of the various materials. The principal aim in arranging suitable mixtures of concrete should be to obtain the maximum density, as this only will give maximum strength. Air-entrained concrete has shown no reduction of strength in tests, despite some reduction in density.

Fine Aggregate.

This should consist of sandstone, slag, granite, or other stone screening from $\frac{1}{4}$ in. down to dust. It should be fine, clean, hard, and durable. It is usual to specify that the sand should be sharp, but round particles are equally, if not more, suitable for dense mixtures

In view of the great importance attaching to the grading of the material for the purposes of denseness, it is advisable to make sieve analyses of the material from time to time as it is being used. The sieves usually employed for fine aggregates in British practice are B.S. Specification.

The analysis conducted with these sieves will indicate the value of sand for mortar and concrete work. The surface area of the sand particles varies with the degree of coarseness, and this determines the quantity of cement required. The sand should be sampled with representative quantities for the sieve tests and also for determination of voids in the fine material. The necessity for washing the aggregate is proved by shaking the sample in a flask or cylinder half full of water. The appearance in colour and the amount of suspended solids will indicate at once the need for washing. This is only a rough test, but it is one that can be readily applied on the site of the proposed works.

Organic impurities in sand, may be determined by shaking a few ounces of the sand in a 3% solution of sodium hydroxide and noting the appearance upon the settlement of the liquor overnight. If it is colourless or light yellow, no organic impurities are present, on the other hand, a brown colour shows that the sand is unsuitable for road work. Washing is generally sufficient to remove most of the impurities usually found in sand deposits

Another test for checking the proportions of the materials is to mix the two aggregates and cement in suitable proportions with water to attain the same consistency as used on the works, when further examination of the proportions of the aggregate and cement may be made in several ways. One method is to place a fresh sample of concrete in a cylinder of water and shake until the whole of the materials are in suspension; on allowing to settle, the coarse aggregate will fall to the bottom first, the sand next, and finally the cement. The depth of the various materials in the cylinder will be a good guide as to the accuracy used in mixing.

Determination of Voids in Sand or Coarse Material.

This test is carried out by measuring the quantity of sand or coarse aggregate in one cylinder, well tamped, and shaken with sufficient water to cover the material, so that the result will not be inaccurate by reason of water absorbed by the dry material itself. Water is then measured in a second cylinder and the aggregate poured slowly from the first cylinder into it.

The voids are then determined by adding the reading of the level of the aggregate to the amount of water taken and subtracting the reading shown at the top of the water.

Proportioning by Voids.

The methods of proportioning dense concrete by voids are based on the requirements that the voids of the coarse aggregate will be filled up by the fine aggregate with a little excess, while the cement will find the voids of the fine aggregate also with a little excess. The surplus allowed in each case is necessary, because the voids of the two aggregates are increased by the insertion of the respective finer materials. Having determined the voids in sand and coarse material, the concrete should be proportioned so that the sand is sufficient to fill the voids of the larger material with an excess of 10% and the cement paste about 10–15% in excess of the voids in the sand. By this means the proportions can be regulated to give the densest practical mixture of concrete. One of the difficulties in attaining a

high degree of accuracy by this method is that of obtaining a correct and representative value in practice for the voids.

As an illustration of this method let it be assumed that the coarse aggregate has 45% voids and the fine aggregate 40% voids.

Take 1 part or 1 cu. ft. of stone:

Then $0{\cdot}55 =$ vol of stone
$0{\cdot}45 =$ voids.

Now fine aggregate must equal $0{\cdot}45 + 10\% = 0{\cdot}495$.

The voids in the fine aggregate are 40% of $0{\cdot}495 = 0{\cdot}198$. Now, cement paste should equal, say, 15% above the voidage in the fine aggregate $= 0{\cdot}198 \times 1{\cdot}15 = 0{\cdot}228$. But 1 cu. ft. of cement powder makes approximately 0·85 cu. ft. of cement paste,

$$\therefore \quad \frac{0{\cdot}228}{0{\cdot}85} = 0{\cdot}268 \text{ cu. ft. cement.}$$

The proportions then are:—

	cu. ft.
Coarse aggregate	1·0
Fine aggregate	0·495
Cement	0·268

Taking cement as one part, these quantities give a proportion of 3·74 : 1·85 : 1.

Proportion of Water to Concrete and its Strength.

One of the most vital points in carrying out concrete roadwork is that of maintaining the right proportion of water in mixing the concrete. It is a common practice to leave this to guess-work, and the natural tendency is to make the concrete too wet or sloppy. A curious fact is that the correct amount of water cannot be determined by the appearance of the mixture, and it is absolutely essential that the proportion of water should be adhered to independently of its condition. An excess of water of 10–15% actually causes a decrease in strength of nearly 50%, hence the necessity for proportioning the water scientifically.

Professor Abrams conducted an exhaustive research into this branch of concrete work and evolved a basis for proportioning water to concrete as a result of approximately 50,000 tests. He states: "Our experimental work has emphasized the importance of water in a concrete mixture, and has shown that the water is in effect the most important ingredient, since very small variations in the water content produce more important variations in the strength and other properties of concrete than similar changes in the other ingredients."*

* Design of Concrete Mixtures Bulletin, No. 1, by D. A. Abrams, Professor, Lewis Institute, Chicago.

Fig 101 shows the percentage of maximum curve in the strength compared with the percentage of quantity of water used that will give maximum strength.

Vertical distances show the relative strength of the concrete with varying percentage of water as a percentage of the maximum which can be obtained from the same mixtures of cement and aggregate.

Horizontal distances show the relative quantity of water used in the mixture, considering the amount which gives the maximum strength as 100%.

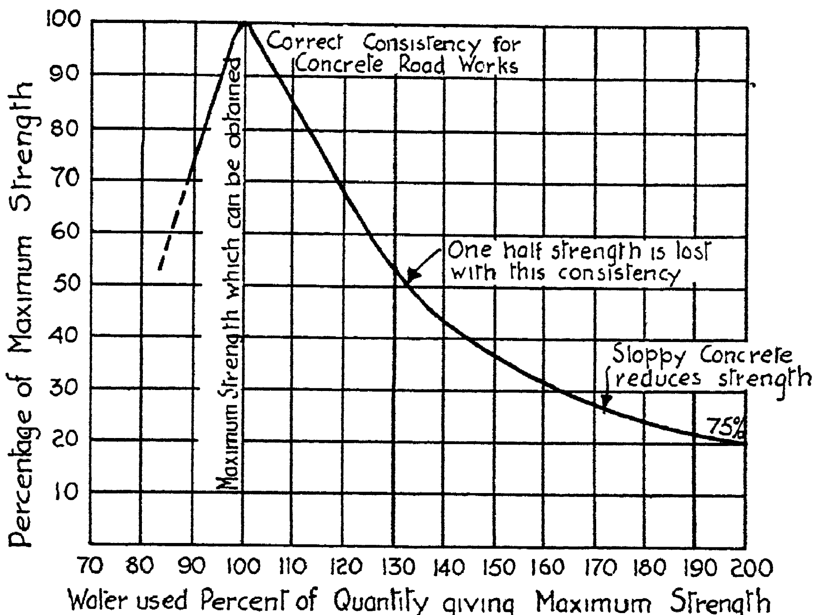


FIG. 101.—GRAPH SHOWING STRENGTH OF CONCRETE COMPARED WITH PERCENTAGE OF WATER USED.

Professor Abrams states, however, that the quantity required is governed by :—

1. the condition of "workability" of the concrete which must be used;
2. the normal consistency of the cement;
3. the size and grading of the aggregate measured by the fineness modulus.

He also gives the following equation for comparative strength of concrete and water content :—

$$S = \frac{A}{B(x)} \qquad (1)$$

where S is the strength of the concrete and x the ratio of volume of water to the volume of cement in the mixture; A and B are constants.

The values of each depend on the quality of cement used, the age of the concrete, and the curing conditions, etc.

For the conditions under which Prof. Abrams' tests were made his formula becomes :—

$$S = \frac{14,000}{7(x)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The curve of Fig. 101 is an average of the results of tests of the several mixtures. He then finds an expression for the water ratio—i.e., *Volume of Water*—in terms of the relative and the normal volume of cement consistency, the fineness modulus, the absorption of the aggregate after three hours' immersion, and the moisture contained in the aggregate.

The normal consistency requires the use of such a quantity of mixing water as will cause a slump or settlement of $\frac{1}{2}$–1 in. in a freshly moulded 12 × 6 in. diameter cylinder of about 1 : 4 mixture upon withdrawing the form by a steady upward pull, the relative consistency or workability factor of 1·10 requires the use of 10% more water, and under the above conditions will give a slump of about 5–6 in.

Profs. Talbot and Richart determine the strength of the concrete by the " cement–space " ratio. This ratio is found by dividing the absolute volume of the cement (c) in a unit volume of freshly placed concrete by the sum of the voids in a unit volume of concrete (v) and of the absolute volume of cement. Thus the " cement-space " ratio is $\frac{c}{v + c}$. If the compressive strength is plotted against the " cement-space " ratio, with basic water content in each case, a smooth curve is obtained.

Fineness Modulus.

The " Fineness Modulus " is determined by making a sieve analysis, using Tyler's standard sieves, in which a clear mesh opening in each sieve is just double that of the preceding one.

A sieve analysis is expressed in terms of either volume or weight as the percentage coarser than each sieve.

The fineness modulus of the aggregate is defined as the sum of the percentage given by the sieve analysis divided by 100.

In actual practice it is almost impossible to attain complete accuracy; it is, therefore, essential to know the amount of variation

Fineness Modulus

Sieve size.	Size of square opening.		Sieve Analysis of Aggregates. Per cent. of sample coarser than a given sieve.						
			Sand			Pebbles.			Concrete aggregate G.[1]
	in.	mm.	Fine A.	Medium B.	Coarse C.	Fine D.	Medium E.	Coarse F.	
100-mesh.	0·0058	0·147	82	91	97	100	100	100	98
48-mesh.	0·0116	0·295	52	70	81	100	100	100	92
28-mesh.	0·0232	0·59	20	46	63	100	100	100	86
14-mesh.	0·046	1·17	0	24	44	100	100	100	81
8-mesh.	0·093	2·36	0	10	25	100	100	100	78
4-mesh.	0·185	4 70	0	0	0	86	95	100	71
$\frac{3}{8}$ inch.	0·37	9·4	0	0	0	51	66	86	49
$\frac{3}{4}$ inch.	0·75	18·8	0	0	0	9	25	50	19
$1\frac{1}{2}$ inch.	1·5	38·1	0	0	0	0	0	0	0
Fineness modulus	—	—	1·54	2·41	3·10	6 46	6·86	7 36	5·74

[1] Concrete aggregate G is made up of 25% of sand "B" mixed with 75% of pebbles "E" Equivalent gradings would be secured by mixing 33% sand "B" with 67% coarse pebbles "F": 28% "A" with 72% "F," etc. The proportion coarser than a given sieve is made up by the addition of these percentages of the corresponding size of the constituent materials.

permissible for the fineness modulus of aggregates. Prof. Abrams' table is given below :—

Maximum Permissible Values of Fineness Modulus of Aggregate

Proportion of cement to aggregate.	Size of Aggregate for Concrete.[1] Limits of grading													
	Meshes per inch.					Inches.								
	0–28	0–14	0–8	0–4	0–3	0–$\frac{3}{8}$	0–$\frac{1}{2}$	0–$\frac{3}{4}$	0–1	0–$1\frac{1}{2}$	0–2·1	0–3	0–$4\frac{1}{2}$	0–6
1–12	1·20	1 80	2 40	2 95	3 35	3·80	4 20	4 60	5·00	5 35	5 75	6 20	6·60	7 00
1–9	1 30	1·85	2 45	3 05	3 45	3 85	4 25	4 65	5 00	5 40	5·80	6 25	6 65	7 05
1–7	1 40	1 95	2·55	3 20	3 55	3 95	4·35	4 75	5 12	5 55	5 95	6 40	6 80	7 20
1–6	1·50	2 05	2 65	3·30	3·65	4 05	4 45	4·85	5·25	5·65	6 05	6·50	6 90	7·30
1–5	1 60	2 15	2 75	3 45	3 80	4·20	4 60	5 00	5·40	5 80	6 20	6 60	7 00	7 45
1–4	1 70	2·30	2 90	3·60	4 00	4 40	4 80	5·20	5 60	6 00	6·40	6 85	7·25	7 65
1–3	1·85	2·50	3·10	3·90	4 30	4·70	5 10	5·50	5 90	6 30	6 70	7·15	7 55	8 00
1–2	2·00	2·70	3·40	4·20	4 60	5 05	5·45	5 90	6·30	6 70	7 10	7·55	7·95	8·40
1–1	2·25	3·00	3·80	4·75	5·25	5·60	6 05	6·50	6 90	7 35	7·75	8 20	8 65	9·10

[1] Considered as "half-size" sieves; not used in computing fineness modulus

For maximum sizes of aggregate and for mixtures other than those given in the table, use the next smaller size and the next leaner mix respectively. For other classes of aggregate reduce values as follows :—

REDUCING VALUES

Crushed stone or slag	0·25
Crushed material unusually flat or elongated . .	0·40
Pebbles consisting of flat particles	0·25
Stone screenings (if machine mixed omit reduction) .	0 25

It is not advisable to use sand with a lower fineness modulus than 1·50 in ordinary concrete mixtures.

Crushed stone mixed with both finer sand and coarser pebbles requires no reduction in fineness modulus, provided the quantity of crushed stone is less than 30% of the total volume of the aggregate.

The following example illustrates the application of Prof. Abrams' investigations in the design of concrete mixtures :—

Take the following aggregates :—

	Coarse aggregate.	Fine aggregate.
100-mesh	100	82
48-mesh	100	52
28-mesh	100	20
14-mesh . . .	100	0
8-mesh	100	0
4-mesh . . .	95	0
$\frac{3}{8}$ in. . .	66	0
$\frac{3}{4}$ in.	25	0
$1\frac{1}{2}$ in. . .	0	0
Fineness modulus .	6·86	1 54

Since more than 20% is coarser than the $\frac{3}{8}$-in. sieve, the maximum size of aggregate is $\frac{3}{4}$ in.

From the table, the maximum value of fineness modulus which may be used for, say, a 5 : 1 mixture is 5·00. Thus by taking 65% of coarse aggregate and 35% of fine aggregate we obtain the necessary fineness modulus.

If
$$P = 100\,\frac{A - B}{A - C}$$

where P is the percentage of fine aggregate in the total mixture,
A is the fineness modulus of the coarse aggregate,
B is the fineness modulus of the final aggregate mixture,
C is the fineness modulus of the fine aggregate,

$$P = 100\,\frac{6{\cdot}86 - 5{\cdot}00}{6{\cdot}86 - 1{\cdot}54} = \frac{186}{5{\cdot}31} = 35\%.$$

Note. The proportions and quantities for 1 cu. yd. of concrete as prepared by Prof. Abrams are given in Appendix III (Table 2).

By reference now to Table 1 in Appendix III the quantity of water may be found for the given mixture and a suitable consistency—say, 1·10

The values obtained on the work will depend on such factors as the consistency of the concrete, quality of the cement, method of mixing, handling, placing the concrete, etc , and on the age and curing conditions.

Strength values higher than given for relative consistency of 1·10 should seldom be considered in designing, since it is only in exceptional cases that a consistency drier than this can be satisfactorily placed For wetter concrete much lower strengths must be considered.

Table 2 (Appendix III) enables the necessary quantities and proportions of aggregate and matrix to be calculated for standard conditions.

This table shows the various proportions by which to combine a variety of fine aggregates of five selected sizes, with various sizes of coarse aggregates. The fine aggregates, or sands, shown in the table include, first, one with all particles passing a sieve with 28 openings per linear inch, and another with 14 openings, one with 8, one with 4, and a sand with $\frac{3}{8}$-in. size particles down. The range of coarse aggregate is apparent from the table

To determine whether a given aggregate is to be classed as 3 in. or $2\frac{1}{2}$ in. or 2 in., or whatever the upper limit of size may be, there should be not less than 10% of the sample between the 3-in. and $2\frac{1}{2}$-in. sizes; otherwise it will be classed as $2\frac{1}{2}$-in. size. Similarly, if there are 2-in. pieces it will be classed as 2-in. aggregate if there is not less than 10% between $1\frac{1}{2}$-in. and 2-in. sizes.

For fine aggregates there should be of the coarser material not less than 15% between the coarser size and the next smaller screen opening. Thus, if a fine aggregate is to be classed as $\frac{1}{4}$-in size, there should be not less than 15% between the $\frac{1}{8}$-in. screen and the $\frac{1}{4}$-in screen.

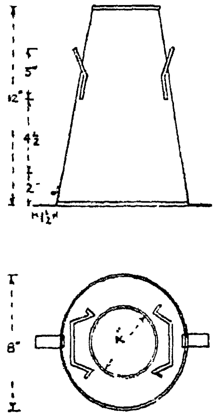
With the $\frac{1}{4}$-in. sand down, the one usually specified, and with the coarse aggregate varying from that held on a No. 4 sieve to that passing a $1\frac{1}{2}$-in. opening, the usual proportions of 1 : 2 : 3 were taken, and, with a workable plasticity or practical consistency, such a mixture produces a concrete with a crushing strength at twenty-eight days of 3,000 lb. per sq. in. in the form of 6 × 12-in. cylinders. All the other proportions and combinations are computed to give the same strength concrete as the 1 : 2 : 3 mixture.

Table 1, Appendix III, enables the necessary quantity of water to be calculated for average conditions.

Table 2, Appendix III, has been determined from laboratory measurements and is compiled for concrete required for road work;

allowance therefore should be made for waste in the aggregate in handling the work, and another table calculated with this table as a basis, when concrete of different quality and strength is required.

The consistency of concrete for maximum strength may be determined by Mr F N Romans' "slump" test. The apparatus used for this test consists of a metal truncated cone 12 in. high, having a base 8 in. and a top 4 in (Fig. 102). This cone is filled with freshly mixed concrete, in four layers each rammed 25 times with a $\frac{5}{8}$ in. diameter steel rod and struck with a trowel. On carefully raising and drawing the mould, the fall of the struck surface is measured 1 min. after withdrawal of the cone For concrete road work a slump of 1–2 in. is permissible; outside these limits the mixture is either too dry or too wet.



Truncated Cone Mould

FIG. 102.—ROMANS' TRUNCATED CONE FOR SLUMP TEST.

A wet consistency of concrete will show a slump of from 4 to 8 in. Furthermore, it should be noted that crushed stone will show a less slump than concrete of the same consistency composed of other materials, owing to the fact that the angular fragments of the former will be held in place mechanically in the mixture, whereas aggregates having a smaller proportionate surface area are not held to the same degree.

MIXING OF CONCRETE AND CONSTRUCTION METHODS

The mixing of concrete to-day is invariably carried out by machine; careful preparation of the subgrade is important to ensure a uniform thickness of slab. A "point template" with metal side-forms set correctly may be used to test the level of the prepared subgrade. On large jobs concrete is deposited from the discharge bucket of the mechanical mixer, while a double screed finishing machine may be used to strike off the surface. The use of mechanical spreaders helps greatly to place the concrete, and it is possible to use a dryer mixture than with other methods; these spreaders may be either the "screw" type or the "paddle" type. It is always important to check the water content, and ample provision should be available to carry this out during progress of the work.

Where reinforcement fabric is to be included in the slab it should be placed in position just before placing the final layer of concrete.

Vibration and Finishing.

This may be done (1) by hand, (2) by power-driven machine, or (3) by a high-frequency vibrator (i.e. 5,000 to 9,000 revs. per min.)

applied to the surface or internally, although the latter method is not well established Vibration enables a drier mixture to be used and the proportion of sand reduced. Mechanical vibration will increase the strength of the concrete by as much as 10%

It is essential to avoid an excess of water or laitence on the surface after vibration, as this weakens the slab and the wearing surface.

Brooming and belting, or light transverse rolling, is sometimes specified, according to the particular finish required. The use of a power-driven longitudinal float and a longitudinal finisher will ensure a smooth-running surface by removing irregularities which should not exceed ⅛ in. with a 10 ft. straight edge

Mixing of Concrete.

The arrangements for handling, measuring, and batching from stock piling are an extremely important part of the efficiency of large-scale concrete road work. The aggregate must be separately weighed with suitable scales into hoppers while cement is measured by the bag

Naturally the water-measuring equipment must be such that only small errors will occur under pressure variations, etc ; consistency must be maintained and generally slump limits between 2 and 3 in. will be necessary. Where consolidation by vibration is employed a 1–1½ slump is sufficient to produce a strong, good-wearing slab.

Site-mixing

Mixers of the batch-mixing " boom-and-bucket " type fitted with timing device may be employed; an operation speed of between 14 and 20 revs. per minute is desirable.

Dual drum or tandem mixers may be used where required; mixing for about thirty seconds takes place in the first drum, and the mixture is then transferred to the second drum to be turned for the same period.

Water should enter the drum slightly in advance of the dry mix and continue until after the drum is fully charged.

Concrete mixed on the site in this manner must never rest more than forty-five minutes before being placed in position. There is a tendency to ignore the accumulation of cement in the drum and in the mouth of the mixer; cleanliness in this respect is essential.

Ready-mixed Concrete

This implies concrete mixed at a central depot from which it is hauled to the job in either (*a*) lorries fitted with agitators; or (*b*) in transit mixers where the mixing is completed en route. In (*a*)

water-tight agitators are used, and it is essential that no segregation should take place after the mix has been transferred from the central plant to the vehicle.

In method (*b*) transit mixers are becoming increasingly popular, sometimes partial mixing (semi-plastic) is done at the central depot and is completed en route—this is known as shrink mixing; otherwise, and more generally, the dry mix is charged into the transit at the depot and water added during transit. The mixing time should not exceed thirty minutes, and this should occur up to the time of discharging on the job and immediately after adding the water.

Air Entrainment.

"Air entrainment" in concrete improves the workability and durability of the road slab; this is brought about by the mixing of air-entraining material into the cement, the effect being the introduction of about 5%, more or less, of air in the form of minute disconnected bubbles in the concrete itself.

Additives used include Vinsol resin (from pine wood) and triethanolamine salts of a sulphonated hydrocarbon.

Air entrainment can be obtained by adding this material directly to the concrete at the time of mixing—a procedure which gives better control; the air content should not be less than 3% nor more than 6%.

There is a slight loss in strength, but this is compensated by the reduction in bleeding and segregation and by the increased resistance to freezing and thawing and the effect of common salt when used for ice removal.

The technique of air entrainment would seem to be contrary to the idea that concrete should have the greatest possible density to be satisfactory. Vibration tends to reduce the amount of the air in air-entrained concrete and tests should be made to determine the allowance relative to the vibration.

Waterproof Paper for Base of Slab.

It is good practice to lay waterproof paper on the prepared base before placing the mixed concrete. If the base is dry the use of this paper makes it unnecessary to water the base; in addition, it prevents loose material from the base working up into the gauged concrete and so weakening the slab.

Longitudinal Joint Construction

Where a road is 20 ft. or more in width, centre joint construction avoids the irregular cracking which takes place when the full width

is formed in one slab: moreover, one half may remain open to traffic or to operational traffic during construction.

The joint serves to control warping and expansion or contraction, and to act as a hinge in the event of movement from the subgrade.

Some examples of joint designs—which includes types suitable for longitudinal joints—mostly employing dowels are shown in Fig. 105; some of the sections show the thickened edge design and give greater beam or cantilever strength: these joints are well suited for runway construction.

The author has found after considerable practice that a "base" or "pad" slab about 2 ft. 6 in. wide will give the necessary support for either a longitudinal or a transverse joint without the use of dowels (Fig. 103); too much bonded steel causes rigidity, thus preventing hinge action; moreover, the base slab prevents water seeping into and weakening the foundation.

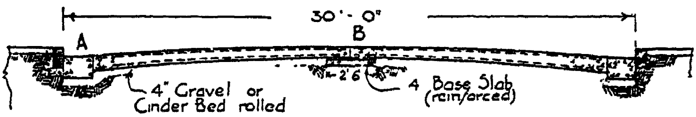


FIG. 103.—BASE SLAB CONSTRUCTION.

The base slab method should be carried out under the following conditions:—

1. It should be constructed in advance of the main slab, to avoid adhesion.
2. The bed of the road should drain away from the centre, and not into the bed of the base slab.
3. Single or double reinforcement (or pre-stressing) is desirable for the main slab for heavy traffic conditions.
4. The edges of the joints should be rounded slightly with an edging tool; if possible, special vibration applied near the face of the forms will improve strength and density.

With this method wheel-loads are not transmitted across the joint, as is the case where dowels are used; in the latter about 90% of the load may be transmitted.

Tests carried out with Ames dials showed that about 40% of the load was carried across a transverse crack $\frac{1}{16}$ in. wide, whereas a 2-in. joint with $\frac{1}{2}$-in. expansion joint caused a 12% deflection on the opposite side of the joint.

Another use of the base-slab construction is at the junction of a concrete slab and bituminous macadam as shown in Fig. 104.

Transverse Joints

These include joints for dealing with (*a*) expansion; (*b*) contraction; and (*c*) warping (Figs. 105 and 106); they may be formed at 90° or at a lesser angle to the line of the road.

Expansion Joints.

Usually these are placed at about 100-ft. spacings, using some pre-moulded board or strip on edge to form the joint and allow for expansion. The expansion and contraction properties of the jointing material do not function indefinitely, and there is a tendency

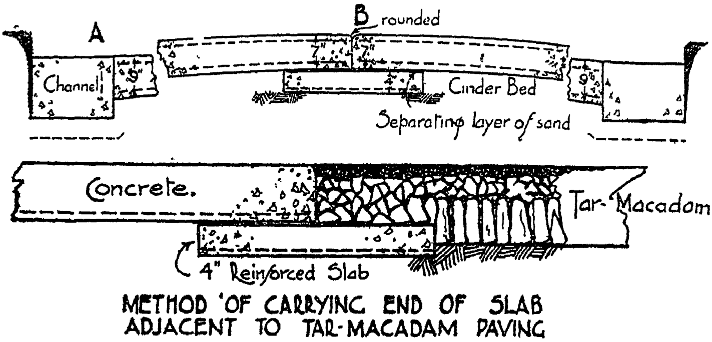


Fig. 104.—Base Slab Construction. Junction of Concrete and Bituminous Macadam.

to-day to allow for expansion to take place at the more frequent contraction or construction joints.

Re-sealing Expansion Joints.

Machines have been designed to clean and re-seal joints in concrete roads; these machines clean the joint and re-shape the arrises by a high-speed rotary cutter and wire brush. A combined air-jet and priming unit blows dust from the joint and applies a bituminous primer in one operation; the sealing compound is inserted from a thermostatically controlled heater.

Contraction Joints.

Concrete pavements contract by loss of moisture and by lowering of temperature; the subgrade resists the contraction and stresses are set up. A slab of 20–30 ft. length and 10 or 12 ft. wide will generally withstand contraction and therefore dummy joints may be formed by either a deformed metal plate or by a deep groove in the surface made during construction.

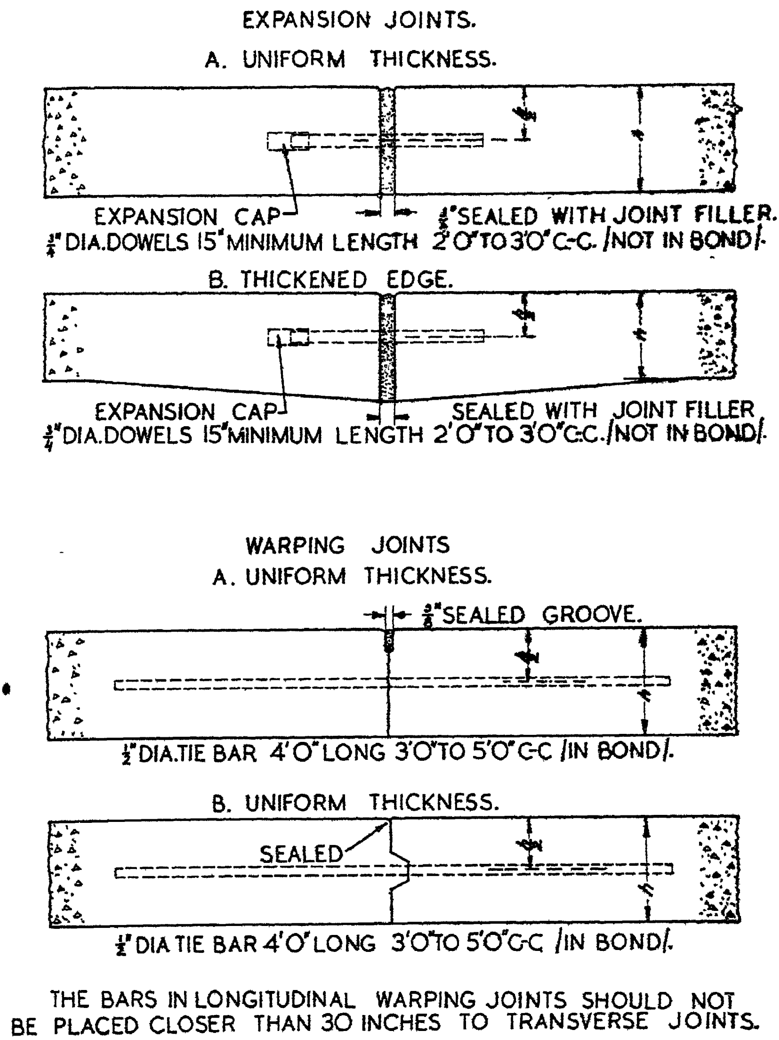


FIG. 105.—DETAILS OF LONGITUDINAL JOINT DESIGNS FOR UNIFORM THICKNESS AND THICKENED EDGE PAVEMENT *(continued overleaf)*

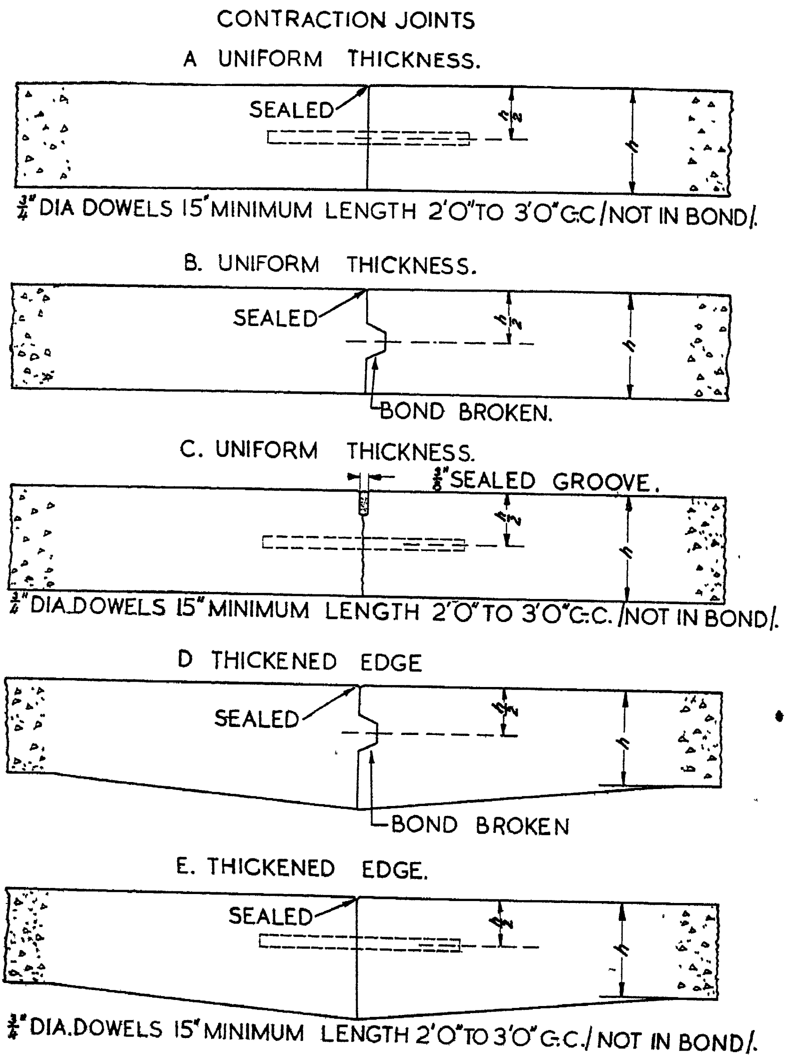


Fig. 105—(*continued*).

not exceeding 18 or 20 ft., or for curves, it is frequently an advantage to arrange for the road slab to be laid with side-fall and gullies provided only on the lower side. To do this some 2 or 3 in. differ-

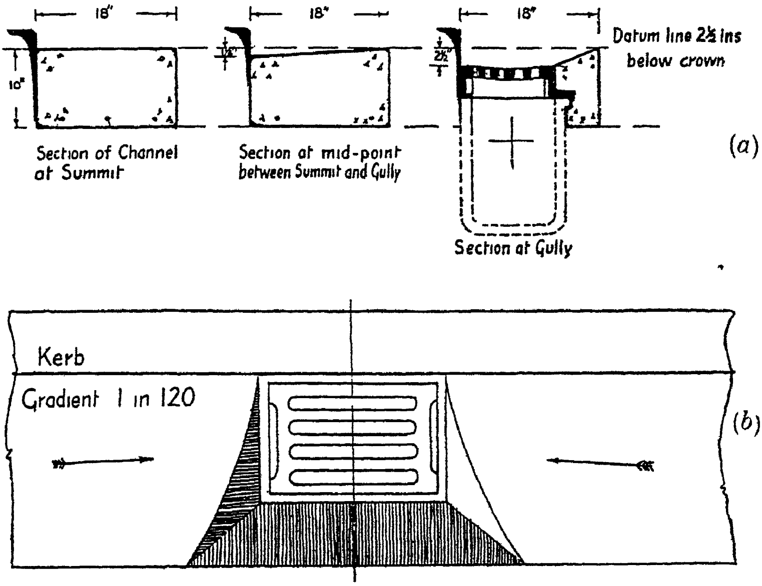


FIG. 108.—CONSTRUCTION OF CHANNEL.

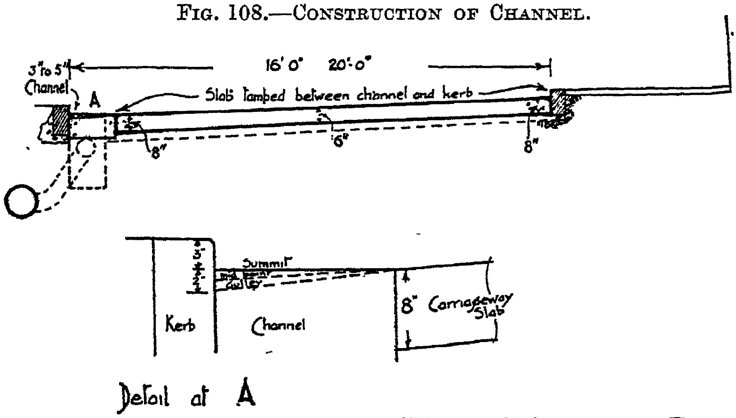


FIG. 109.—SIDE-FALL ROAD WITH "DIPPED" CHANNEL IN FLAT DISTRICTS.

ence of level between the kerbs on either side should be allowed where possible, so that an equal depth, at the face of the kerb on each side, may be obtained (Fig. 109).

A further merit of this construction is that the surface-water drainage may be confined to the footpath on the lower side, with

some saving in cost and without any disturbance to the foundation of the road.

With non-rigid roads it is desirable to finish to a half-camber shape to allow for any slight wear or depression holding water.

Finishing the Slab.

The finishing of the concrete surface is a process requiring careful supervision and considerable skill on the part of the operators. In many cases tamping is considered sufficient to provide a regular surface which will not be too smooth. Surfaces may also be finished by floating from a bridge with wooden floats, by rolling transversely with a long-handled or rope-drawn roller, 6 in. diameter and 6 ft long, weighing about 100 lb, until water ceases to come to the

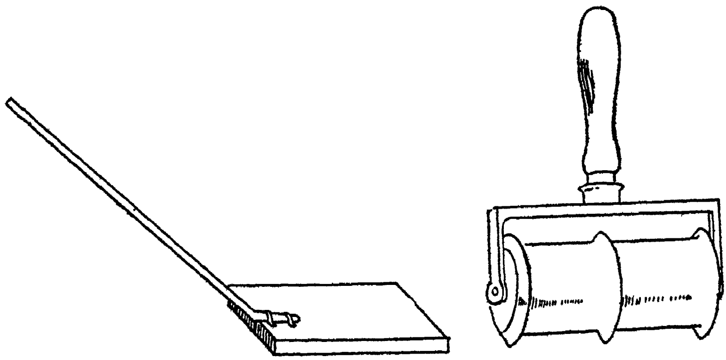


Fig. 110.—Surface Float and Grooving Roller for Finishing the Slab.

surface; or by belting with a canvas or rubber belt—transversely and with a see-saw movement—not more than 12 in. wide, with sticks nailed across the ends for handles. These processes compress the concrete, reduce the voids, and force out the surplus water.

Fig. 110 shows a surfacing float which is manipulated by a long handle, and an impression roller for grooving concrete paving; the roller is used after the concrete has taken its initial set.

Curing and Protection.

After the finishing of the concrete surface it is necessary to take further steps to obtain a hard-wearing pavement. In the first instance some protection from animals, and in town districts also from children, until the concrete has set hard enough to bear such weights, is essential, and close fencing may become a necessity. Wire-netting or split oak fencing is very suitable for this purpose.

When the concrete is sufficiently hard—i.e. after about 1–2 days—it should be "cured" for a period of two to three weeks. Curing

may be accomplished in a variety of ways; for example, calcium chloride or silicate of soda may be applied; other proprietary articles may be mixed in the wearing course to accelerate and intensify hardening; rapid-hardening cements are useful where early strength is required; finally we have the ordinary method of curing by keeping the surface wetted for several days after laying. This may be effected by: "ponding"—a process of building clay dams at the sides and across the road to retain a depth of about 2 in. of water; or by covering with a 2-in. layer of wetted earth, sand or better still sawdust, cotton mats, wetted straw or waterproof paper, sawdust can be used over and over again.

Recent comparative tests on hardening prove that curing by "ponding", or by covering with moist earth, is generally the most satisfactory.

It is extremely important to maintain the concrete in a wet condition for the first three or four days when the strength is developing most rapidly; after this period the rate of hardening slows down, and it is to some extent of less importance to continue watering. The cost of applying silicate or soda, in addition to the usual method of watering or damping, is very small in proportion to the benefit obtained in improved wearing qualities.

Strength tests may be made at periodic intervals on test-beams cured under the same conditions as for the road-slab. The slab is sufficiently strong for traffic when the test beams show a modulus of rupture of about 550 lb. per sq. in.

In a wet country like Britain excellent concrete wearing surfaces may be obtained when a gentle rain falls immediately after tamping. Even a heavy downpour will not entirely spoil the slab, it will merely leave the aggregate above the mortar rather high, a condition which may well stand up to the wear of traffic.

In hot, sunny weather the new concrete should be protected immediately by placing over it canvas or tarpaulin shades.

In hot weather the crown of the road—which, of course, has the greatest wear—dries very quickly, both after laying and later, after sprinkling, and curing is rendered ineffective for the middle portion of the road. In this manner the wearing qualities may be seriously impaired where traffic is the heaviest.

Generally traffic should not be allowed to pass over the road until a period of at least two weeks has elapsed from the laying of the last section in mild weather, and for a longer period in cold weather. This closing increases the cost of the work by the additional watching and lighting. In some cases it would be advisable to close the road after, say, two weeks only during the daytime and open it during periods of darkness. This dispenses with lighting and also night watching.

In late autumn or early spring, when frosty nights are possible, great care is necessary to prevent a sudden fall of temperature from injuring the concrete. A layer of straw, straw matting, or similar material applied to the surface will prevent freezing. As a general rule, concreting should not be permitted in frosty weather.

The frictional resistance of the base of the slab causes transverse cracks to occur in plain concrete. Tar paper beneath the slab will reduce the irregular cracking.

Prof. H. M. Westergaard shows that a shrinkage of 0·0003 in. per in. would produce stresses of about 1,000 lb. per sq. in., equivalent to a fall in temperature of 50° F. With a 5,000-lb. wheel load at 4 in. from each face of a corner of a 7-in. slab, the maximum combined stress is 218 lb. per sq. in.

Curing by Membrane.

A popular method of curing is the application of colourless membrane sealing compounds. Numerous materials are now available for this purpose, and generally they give fairly satisfactory results; the object is to conserve the water content.

Hand-sprays have been superseded by mechanical multiple-spray devices mounted on frames which ride upon the forms, otherwise they are placed on the footpath.

Cold emulsion applied at a rate of 5–6 gals. per sq. yd. is an effective cover; if need be, two coats will make a more effective seal. The liquid used should be colourless and non-slippery, and should harden within thirty minutes; it should be applied immediately after the finishing of the surface; membrane with whitewash is more efficient than the colourless application.

Use of Small Mixers.

A convenient size of mixer for all-round purposes is one which will mix half a cubic yard of concrete in one operation.

Small mixers have the advantage of turning out the mixture speedily, and thus maintaining a constant supply of fairly uniform quality, whereas with the large mixers it may happen that the last portion of a batch is of different strength and consistency from the first portion. The raw materials are gauged and fed into a hopper at ground level, which is then raised to such a position that they deliver into the rotating drum, the outlet of which is closed. Water is immediately passed into the drum, and the whole of the contents are revolved until thoroughly mixed together, a process which occupies about one minute. The speed of rotation depends largely on the capacity of the mixer. For a mixing of ½ cu. yd. a speed of 12–15 revs. per minute is sufficient. Smaller mixers should be re-revolved at 15–20 revs. per minute.

Treatment of Formation—Placing the Concrete

The process of placing the concrete in position, although appearing to be a simple operation, is a matter requiring considerable skill on the part of the operators engaged on the work. As in the case with bituminous road surfaces, uniformity in subgrade, and in the mixture, thickness, density, and consistency of the concrete are the principal points requiring special care. It is comparatively easy to obtain uniformity of this character during 1 day's work; it is much less easy, however, to obtain it from day to day owing to the ever-changing weather conditions.

The greatest possible attention, therefore, should be given towards securing uniform conditions with the subgrade. Ground which shows signs of excessive water should be treated as in the case of an ordinary macadam road. It is of the highest importance that efficient subgrade drainage should be provided for the concrete slab to ensure against failure: it is unnecessary to elaborate here upon

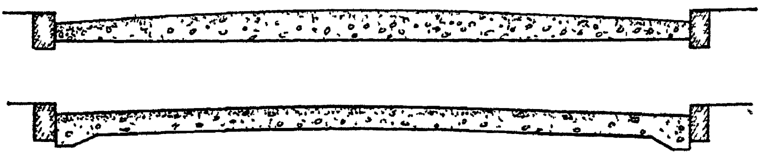


FIG. 111.—SECTIONS OF UNREINFORCED SLABS WITH HORIZONTAL BASE AND WITH CAMBERED BASE. FOR 16-FT. ROAD OR LESS.

this point, except to say in broad terms that the engineer must aim at creating as far as possible a sub-grade which shall be consistent in its bearing power, etc.

Generally it will be found of advantage to excavate the ground to a level which will allow of a cinder bed being laid and rolled before placing the concrete. The contour of this foundation should be the same as that of the finished surface rather than completely horizontal (Fig. 111), since, apart from other considerations, it is not advisable to make the slab thinner at the sides than at the centre; breakings or failure are more likely to occur at the edge of the road than in the middle, especially in the absence of an additional thickness or reinforcement, or of integral kerbs.

The concrete should not be placed in position if the foundation is frozen or is excessively wet or too dry, as in either case the consistency or water-content of the concrete will be affected before the initial set. In the case of a dry subgrade it is perfectly easy to damp the foundation so that it will neither absorb nor exude water when the concrete is placed over it.

The method of conveying the concrete from the machine to the bed depends on the amount of space available adjacent to the road.

Where possible a movable mixer with a delivery arm, as shown in Fig. 112, which can be run alongside the road, will be found to be the most convenient and economical machine. Another method of utilizing the delivery arm for distribution is to place the mixer in the centre of the road and move backward from the completed work

In congested areas, however, this is sometimes difficult, if not impossible, and other methods of transporting the mixed concrete have to be devised. In such cases the concrete may have to be transported on small trucks and rails or handcarts; sometimes, indeed, the wheelbarrow must be utilized as a last resort, and with excellent results, as this enables the concrete to be placed in its correct position.

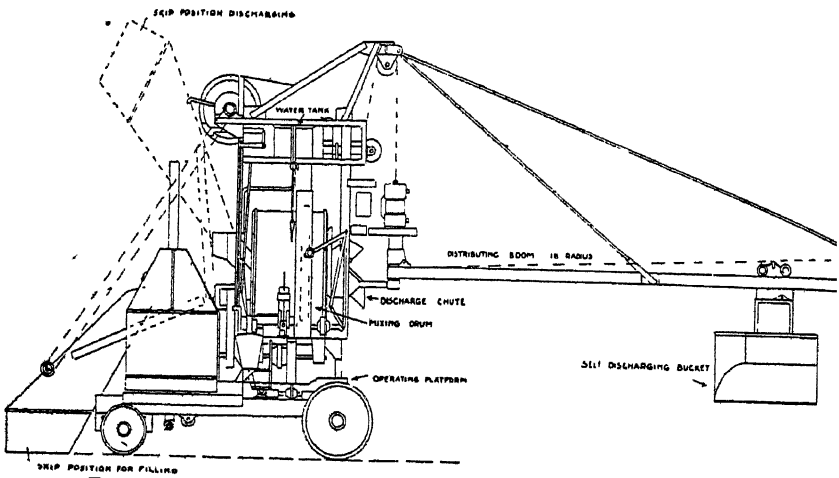


FIG. 112.—BATCH CONCRETE MIXER WITH SELF-DISCHARGING BUCKET.

Single and Two-course Slabs.

In this country there has been a tendency to construct pavement slabs in two-course work rather than in single-course formation, the theory being that a granolithic wearing course will furnish greater strength and offer a harder wearing surface to traffic than the remainder of the slab; also, to use a cheaper aggregate and mixture for the base course will cheapen the cost of the whole slab.

Certainly two-course slabs have given good results where other conditions such as foundation, width, and other factors are favourable. At the Washington Roads Congress, 1930, some trouble arose between the British Delegation and the American Committee because the former desired to emphasize the need for two-course work on the more heavily trafficked roads, whereas the American engineers, having laid many thousands of miles of single-course work on their main roads, could not accept this view.

Eventually it was agreed, and adopted as one of the conclusions, that a two-course pavement with the upper layers composed of very hard aggregate should be used, instead of single-course pavement, where a large volume of steel-tyred traffic is encountered. As a further conclusion, however, it was stated "that single-course pavements have successfully carried maximum volumes of traffic, and maximum wheel loads when the traffic was largely rubber-tyred".

The ultimate decision as to the type of slab and aggregate must be left to the engineer knowing all the circumstances of the case, and bearing in mind the fact that each road requires special consideration and treatment.

Monolithic Work Essential.

It is of the greatest importance that the concrete slab, whatever its number of courses, should be *absolutely monolithic*, and that the work be carried through progressively, and finished at the end of the day at some definite point. With two-course work, composed of a richer and finer concrete in the top layer than in the bottom, the two separate mixings of concrete should be carried out simultaneously, so that the deposition of the coarse concrete precedes slightly that of the wearing course; the latter will not be more than 1 or 2 in. thick as a rule, so that if laid in this manner the whole slab becomes one mass.

Templates and Tampers.

The templates for shaping the road longitudinally and transversely must be fixed with the greatest possible care. Where a longitudinal fall exists the templates may be fixed at either side of the road and the centre; the surface is shaped by a tamper or screed operating between the side forms, which may be of timber or steel, and which must be firmly fixed to maintain the correct levels.

Where the road is not particularly wide, the tamper can be handled quite easily by men on each side of the road. It is an advantage to have a heavy tamper rather than a light one, but this of course imposes a considerable strain on the operators, and additional assistance becomes necessary.

The object of tamping is to enrich the upper layer of concrete, to remove the voids, and thereby render the wearing course as dense as possible; and a heavy tamper accomplishes this with greater certainty than a light one. The tamper may consist of a board about 9 in. by $1\frac{1}{2}$ in., steel shod on the lower edge (Fig. 113). Hand tamping is greatly improved by placing a small vibrator on the tamper.

The shaping and tamping of the concrete can be more easily carried out by a mechanical device, known as a tamping template or tamping machine, thus vibrating the concrete.

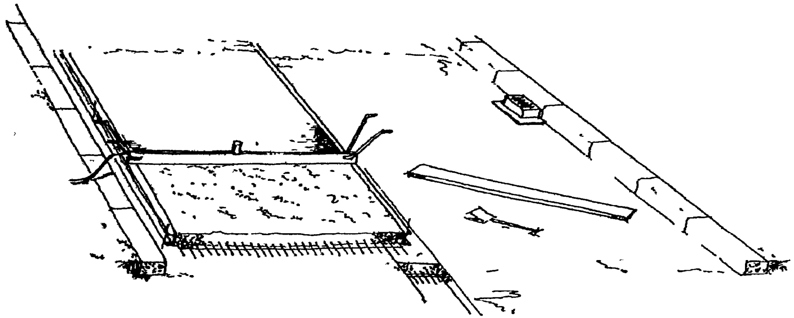


FIG. 113.—HAND TAMPER FOR TAMPING BETWEEN TWO FORMS.

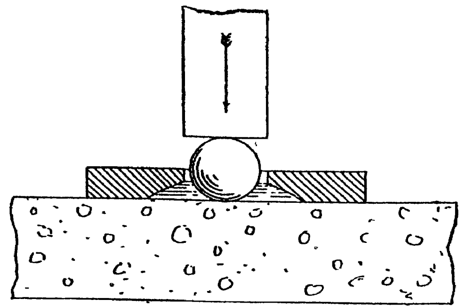


FIG. 114.—BALL TEST FOR HARDNESS OF CONCRETE.

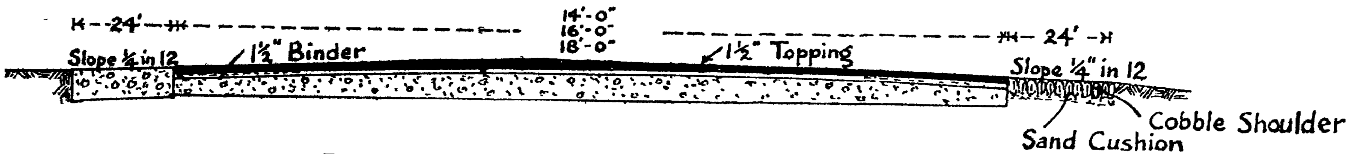


FIG. 115.—OLD CONCRETE ROAD WIDENED AND RE-SURFACED.

Tamping by Machine.

The complete outfit for machine finishing includes a power sub-grader, a mixer of 1 cu. yd. or more, a power-driven machine for spreading, and a finishing machine for smoothing off the concrete; a power-driven longitudinal float may be used for removing transverse irregularities—the machines should be able to work on curves.

In some cases the finishing machine operates a belt for finishing the surface.

Where roads are very wide or very flat longitudinally the arrangement of the template may require modification; where gullies are placed in the channel itself the usual artificial gradients may, of course, alter the shape of the road somewhat from point to point. One method of obtaining this quickening of crossfall towards the gullies is to adopt the alternate bay construction.

Ball Test for Surface Hardness.

This test consists of placing a $\frac{1}{2}$-in steel ball in a holed steel plate 2 ft. × 2 ft. × $\frac{1}{4}$ in. on the concrete surface, as shown in Fig. 114, and applying a load by means of a motor-lorry and jack. The ball is thus pressed into the concrete and the loads registered until the ball has penetrated $\frac{1}{4}$ in., when the load comes directly on to the plate. The test is very simple, and is useful for determining whether the curing process has been satisfactory or not, and whether the surface is sufficiently hard to withstand steel tyres of heavy traffic.

Examples of the Use of Concrete for Improving Roads

1. *Widening at Bends.*

This has already been alluded to in an earlier chapter. Concrete is exceptionally suitable for widening or improving the superelevation at bends; it can be laid on the inside or outside of the bend as a mere addition, leaving the old roadway almost untouched. Thus a concrete strip supporting the edges of the existing road-metal is obtained. Outside widening, together with suprelevation at a bend, may prove a most valuable improvement where inside widening is impossible.

2. *Widening Narrow Macadam Roads.*

As shown in Figs. 91 and 93, concrete strips may be laid at each side of a narrow road without disturbing the surface, except perhaps by re-surfacing with a bituminous wearing course. In such cases the camber may be reduced by raising the concrete strips or channels about the edges of the old macadam. An example of re-surfacing an old concrete road with bituminous wearing course is shown in Fig. 115.

3. *Centre Strip of Concrete.*

In many cases it will be a distinct advantage to substitute for a worn carriage-way a centre strip of concrete about 10 or 12 ft. wide, making good the adjoining haunches with tar-treated material or old sett paving, as the case may be. This provides a good road for the bulk of the traffic, and it is only when vehicles pass each other that the side surfaces come into operation In addition, a concrete

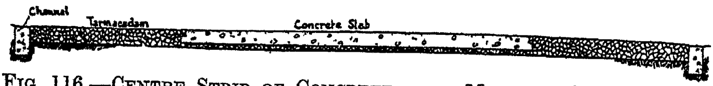


FIG. 116.—CENTRE STRIP OF CONCRETE WITH MACADAM HAUNCHES ON QUIETER ROADS.

channel on either side may be laid to strengthen the haunches (Fig. 116).

4. *Strip Roads in Concrete.*

It is a good plan in certain cases to lay concrete strips or wheelers to carry traffic in the centre of the road, the space between and outside being formed in some cheaper local material. In Southern Rhodesia concrete strip roads balanced with handy earth materials have been remarkably successful. Later the centre is filled in with tar macadam, and in the final stage a 20 ft. road is made by covering the concrete strips with a thin asphaltic wearing course.

5. *Laying Concrete, One Half Only.*

As a means of economy, or widening, this method is commendable, because one side of the carriage-way may remain undisturbed and a greater length of new work provided for a given expenditure than if the whole width were relaid. At a later date, of course, the other half may be laid in concrete. In many cases the old macadam may be scarified and utilized as aggregate for the bottom course of the concrete. It is more advantageous to do this than to lay a thinner slab on the undisturbed macadam. Fig. 117 shows this method of construction with strengthening at the centre and at the channel.

FIG. 117.—HALF WIDTH CONCRETE AND REMAINDER MACADAM.

Increasing the Bearing Power of Clay Soil Carrying a Concrete Slab.

Where road-slabs have settled on weak clay soil, holes may be drilled at 7–10 ft. intervals, and cement grout pumped through

2-in. hose: a 4 cu. ft machine working at 100-lb air pressure is suitable for the purpose.

The leanest mixture is 1 : 2 mix with 7 gal. water, without clogging the machine. The slab is thus raised to its original level: the holes not in use are stopped up by weighted plugs. Further cement is pumped in under high pressure; soda may be added to cement to hasten setting.

The effect of this grouting is to compress the clay subsoil as much as 15%.

Coloured Concrete Paving.

Objection is sometimes taken to the white or dull grey appearance of concrete paving, particularly where it is used for private streets in good residential areas. An improved or "warmer" tone may be obtained by using a coloured aggregate such as red or pink granite or gravel with sand and rapid-hardening "Colorcrete" cement.

Other colours, such as yellow or green, may be obtained by suitable variations of aggregate and cement for the wearing course. Coloured traffic lanes are useful to indicate a special lane for turning off, for instance, at grade separations or to distinguish "lay-bys".

Alternate (Slanting) Bay Construction.

The Walker-Weston system developed an alternate bay construction with slanting transverse joints. The method of laying concrete in alternate bays as general practice has, however, been largely discontinued in favour of continuous work.

Strengthening Joints, Edges and Corners of Slabs

This may be accomplished by the insertion of extra steel as shown in Fig. 118. Slab fractures are likely to occur at these points, particularly at the corners, and the steel will provide the additional strength required to prevent cracking. In otherwise unreinforced slabs corner reinforcement alone laid in the upper part of the slab is often used to afford the extra strength at the weakest part—viz. the corners.

Another method of strengthening a slab which has been tried is to lay reinforced-concrete beams V-shaped across the joint and along the centre joint longitudinally; the transverse beams, at about 6-ft. centres, are anchored into the slab (Fig. 119).

This method is somewhat similar to the base slab, shown in Fig. 103, which may be used for transverse joints as well as for longitudinal joints.

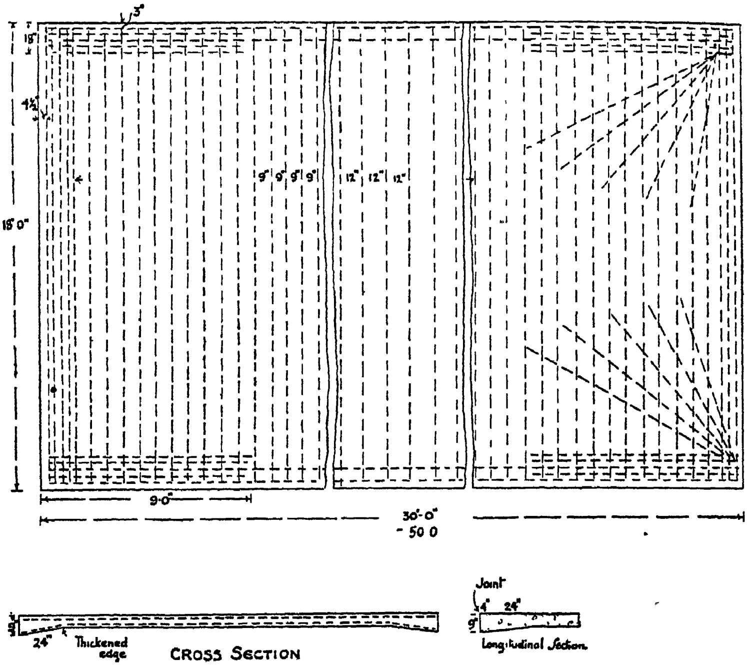


FIG. 118.—METHOD OF STRENGTHENING EDGES AND TRANSVERSE JOINTS WITH ADDITIONAL STEEL.

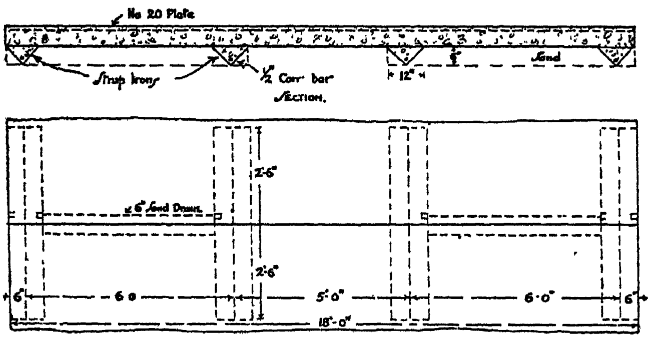


FIG. 119.—METHOD OF STRENGTHENING TRANSVERSE JOINTS BY V-SHAPED R.C. BEAMS.

Blow-ups and Warping.

Occasionally a "blow-up", or burst, occurs in a concrete road. This is caused by expansion due to rains followed by a considerable increase of temperature.

Rounding off the edges of joints will prevent excessive surface pressures due to warping; warping may cause a difference of level

of as much as $1\frac{1}{2}$–2 in. between centre and edges during the winter and spring.

Rubber Asphalt Joint Filler.

Rubber asphalt blends used as joint fillers in concrete pavements have been found superior to the more common types of hot poured materials. Care is needed to avoid over-heating of the material at the time of pouring, if the efficiency is to be maintained.

Pre-stressed Concrete Roads

One of the most important developments in the use of concrete is the introduction of pre-stressed high-tensile steel; this is now being tried experimentally for concrete road construction at Crawley and elsewhere.

Compression Joints.

An alternative method of securing compression, while eliminating expansion joints, is to insert at intervals (of about 400 ft.) special compression joints through which compression can be applied to the slab. The various forces at work on a thin concrete slab, such as temperature and moisture changes, make the use of pre-stressing a more delicate operation than in other cases where it has been used advantageously.

At Crawley the slab was 400 ft. long by 24 ft. wide laid in half-widths with one transverse joint midway; twelve cables, 2 mm. diameter and 8 ft. centres were laid at an angle of 28° with the centre line of the road; the cables terminate at the edge of the slab with cones embedded in high-grade concrete for straining with Freyssinet jacks. Compression in the slab was induced longitudinally and transversely, and after one year the road showed no depreciation.

The tensioning of the cables closed up the prior initial cracks which occurred during hardening.

The maximum expansion seems to be quite small—i.e. about 0·60 in. measured at each end; this compares with about 3 in. on an unstressed slab.

Other tests are being carried out at the Research Station of the Cement and Concrete Association; these include the use of longitudinal cables stressed at the ends.

It is important to note the economic aspect of pre-stressing for concrete roads; it saves about 70% steel against the usual reinforcement, and there is a reduction in the thickness of the slab.

The slab is flexible, and therefore produces a wide area of load distribution; thus, it is well suited to weak sub-grades, such as occur sometimes in damp low-lying districts.

CEMENT-BOUND OR GROUTED CONCRETE ROADS

An interesting development in concrete surfacing is the construction of the "cement-bound" road; this has been widely used with considerable success. Cement mortar is worked into the interstices or voids of the macadam stone by means of rolling. The method is sometimes used for re-surfacing on top of an old road.

Advantages.

The advantages claimed for this type of road are, briefly :—

1. Low initial cost and maintenance.
2. Simple construction, minimum amount of plant and skilled labour required.
3. The surface is non-skidding, will not corrugate, and is suitable for steep gradients.
4. All voids are eliminated in the slab, which compares very favourably with dense concrete slab.

There is only one feature which might be regarded as disadvantageous, viz. the danger of rolling the mixture after the cement has taken its set.

The "Sandwich Method."

There are several methods in this type of construction, the most popular perhaps being the "sandwich" system. A prepared foundation of well-drained and rolled ballast is spread with a 2-in. layer of macadam stone of about 2-in. gauge; this is lightly rolled and watered. Cement mortar (1 part cement to $2\frac{1}{2}$ parts of sand) is then spread over the stone, of a thickness sufficient to fill all voids. This is followed by a second layer of broken stone which is rolled with a 6–8-ton or 10-ton tandem roller, the stone being watered as required. In the process of rolling, the mortar will work up to the surface, which is then brushed to fill all voids and to present a uniform surface. About 180 traverses should be made to ensure complete compaction. This surface should be protected in the usual manner from heat or frost, and should be kept in a moist condition for about seven days. In the case of ordinary cement a further seven days will be required before the road is ready to be opened for traffic. If, however, rapid-hardening cement is used, the road will

be ready a few days earlier. A diagram of a section of a typical cement-bound road is given in Fig. 120.

Australian Practice in Cement Grout Construction.

Cement grout construction has been developed to a considerable extent in Australia

A top grouting or penetration system was introduced by Mr. W. T. Sunderland, City Engineer of Sandringham (Vict.). This consists of rolling a 4-in thickness of $2\frac{1}{2}$-in. gauge metal, then laying fabric reinforcement and a further 4 in. of $2\frac{1}{2}$-in. metal, shaped and

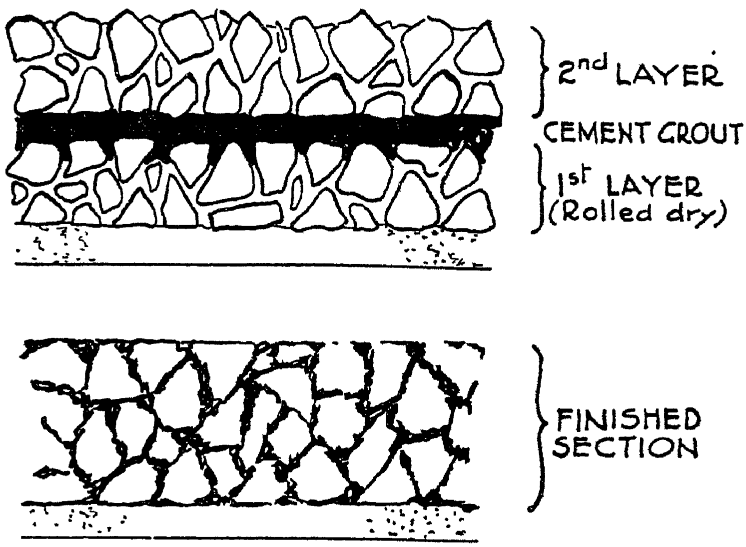


FIG. 120.—SECTION OF A TYPICAL CEMENT-BOUND ROAD (SANDWICH TYPE).

consolidated. Grout consisting of 1 part cement to $2\frac{1}{2}$ parts sand and 7 gallons of water per cu. ft. was mixed to proper consistency and poured into the road directly from a special mixer until all voids were filled. Prior to the initial set, rolling by a 2-ton tandem roller was performed, until the grout was brought to the surface. This finish was not sufficient to give the wear of an unsurfaced concrete road, and a special finish with plastic concrete was introduced. If $\frac{3}{8}$-in. chippings or screenings are rolled into the excess grout, finishing may be carried out by light rolling by hand and belt or squeegee, with good results.

The "plastic" finish requires a suitable concrete mixture of $\frac{1}{2}$-in. slump, which is tamped or rolled, screeded and belted on the top of the road-metal before the initial set. This method allows an

inferior stone to be used in the main slab, and a granite aggregate in the finishing surface, as a wearing coat.

The proportions of the mixture for a road of this type with 1 : $2\frac{1}{2}$ grout approximate to 1 : $2\frac{1}{2}$: 12, giving percentages of 6·5% cement, 16·1% sand, and 77·4% metal.

Experiments show that the grout will flow completely to the bottom of the stone (up to 15 in. of depth), and will then build up and flow along the bed with a gradient: excess water flows ahead, thus wetting the stone and bed in advance of the grout.

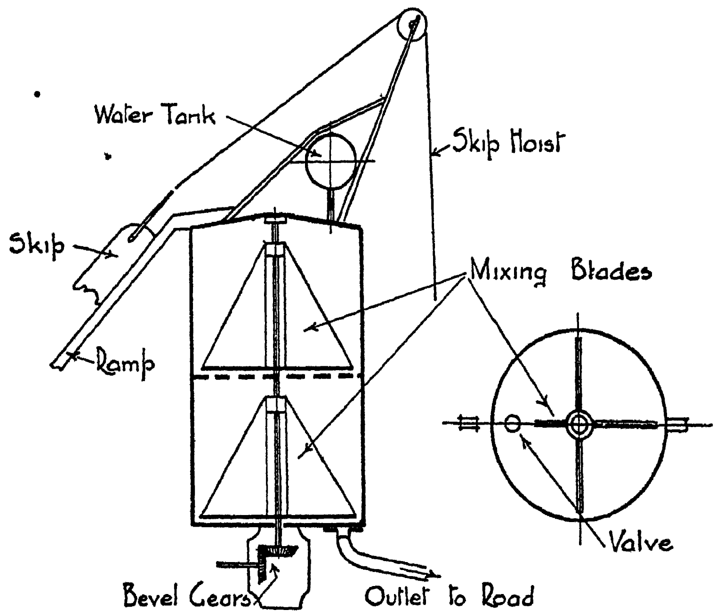


FIG. 121.—BATCH-MIXING MACHINE FOR CEMENT-GROUTED ROADS.

Compression tests on specimens cut from the road show a crushing strength of 4,000–5,000 lb. per sq. in. after three years. Tests on specimens cast separately furnish much lower values, owing to the lack of the true compression obtained in the road bed.

An increase in the time of mixing in a batch-mixer up to as much as five minutes, increases the compressive strength of the concrete.

Vibratory effect is caused in the process of rolling and the road metal is thoroughly interlocked.

Experiments have been tried using cement impregnated with bitumen; it is claimed that this retards setting, expels surplus water and makes the grout more " workable ".

The Batch-mixing Machine consists of two mixing cylinders, one above the other; the mixing being performed by mixing

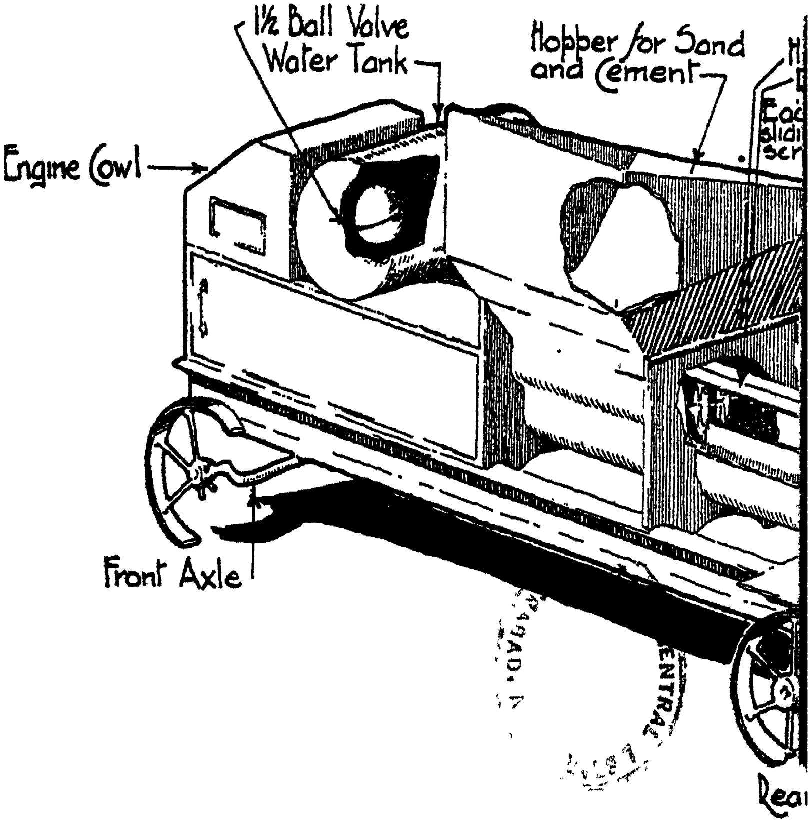


FIG. 122.—CONTINU

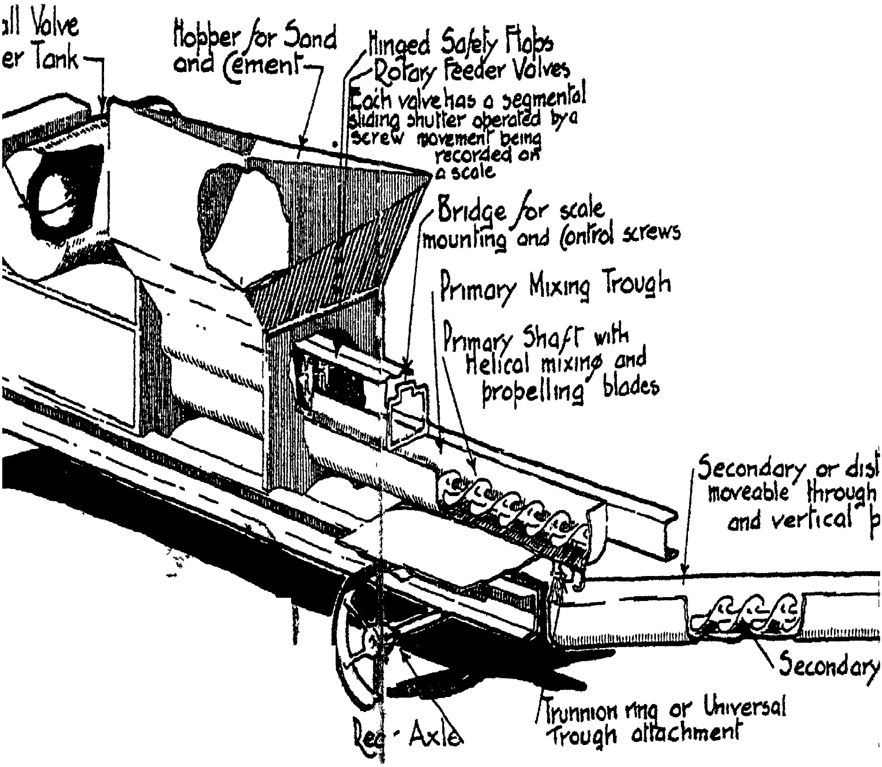
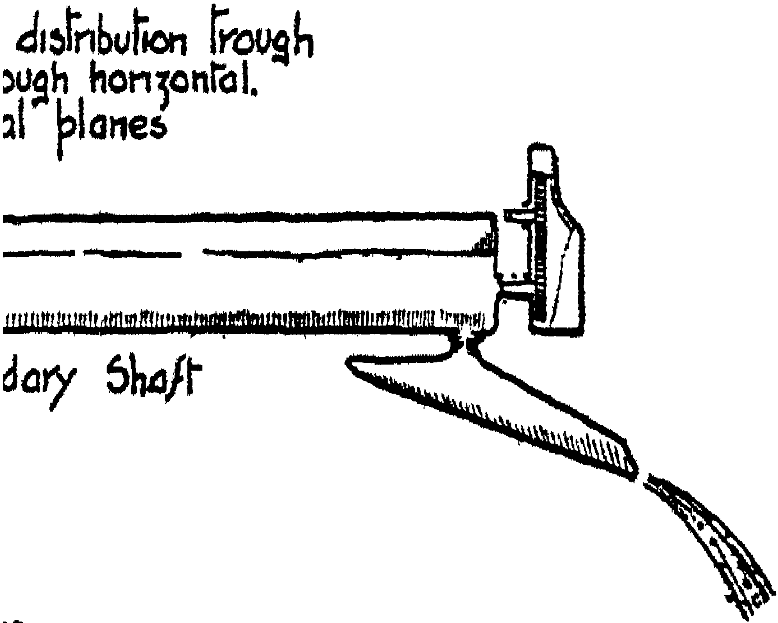


FIG. 122.—CONTINUOUS BATCH-MIXING MACHINE FOR CEMENT-GROUTED ROADS.



os.

To face p. 188

blades on a vertical shaft in each cylinder, driven from the engine of a motor vehicle. Water is added to the first mixing drum and is followed by the charge of cement and sand delivered by skip (Fig. 121). The contents are then passed to the lower mixing drum to maintain continuous agitation, and then poured on to the road through a rubber hose.

The Continuous Mixing Machine consists of a mixing trough with many blades driven at constant speed. The cement and sand are proportioned and fed into the machine from slotted cylinders rotated horizontally at constant speed at the base of the sand and cement bins. Cement, sand, and water fall into the mixing-trough, in which the blades mix and then force to the distributary arm, which also contains mixing blades, and is capable of swinging within an arc of 180°. The grout falls through a chute on a two-way pivot giving a radius of 15 ft. for distribution (Fig. 122).

CHAPTER XVII

FOOTWAYS

UNDER the Road Traffic Act 1930, Sec 58, proper and sufficient footpaths must be provided on all roads wherever necessary. Footpaths vary considerably in width and type; a usual preliminary is the construction of a kerb and channel.

Kerbing and Channelling.

The primary uses of kerbstones are :—

1. To act as a guide to traffic, particularly during dark or in foggy weather.
2. To assist in guiding surplus water from roads and sidewalks into gulleys.
3. To define, support and protect the footpath; also, to a limited extent, to take thrust from the carriage-way.

If natural stone is used, the choice lies between grit rock and non-slip granite. The dimensions will vary according to circumstances, such as type of road and facilities for supply.

The kerbstone may be laid with the broad face upwards—this gives a good appearance—or as edging with the narrow face upwards.

Common sizes are 10 or 12 in. wide by 6 or 8 in. thick; the length is usually about 1 yd.

The kerb face should be tooled, in the case of natural stone, to the slope of the footpath; the edge, or arris, is often chamfered, as also is the vertical face when concrete edgings are used; the height above carriage-way should be about 4 in. Kerbs intended to prevent vehicles from leaving the pavement as a safety measure should be at least 9 in. high, with a batter of 1–2 in.

The kerbs may be laid on a 4-in. bed of cinders, with the joints set in lime mortar; in busy or narrow roads they should be laid on at least 4 in. thickness of concrete. Kerbs may be painted white or yellow to give greater reflection of light; red or white reflector dots set in the kerbs at frequent intervals have been found helpful to traffic; kerbs have been tried with a series of depressions or raised ribs to give a high visibility, but so far these are experimental.

Recent developments in method of air-entrained cement and concrete show that kerbs need not deteriorate or disintegrate by the action of frost to the same degree as hitherto.

Combined Kerbing and Channelling.

This type of kerbing is comparatively cheap and convenient to lay, it may be precast or cast *in situ*; alternatively, it may be built integrally as part of a concrete (3 or 4 to 1 mix) pavement laid *in situ*. Examples of this construction are shown in Fig. 123

One advantage of a combined unit is that greater strength and bearing are obtained to resist pressure and impact from wheel-loads.

Submerged concrete kerbs or channels only may be laid along the channels on rural roads to take the thrust from the carriage-way.

Channel blocks in the past have been formed of granite; today precast blocks are laid on concrete or the channels are laid *in situ*.

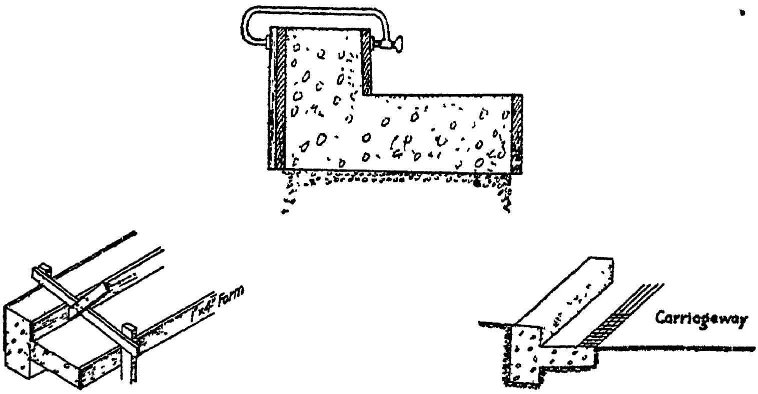


FIG. 123.—METHOD OF CONSTRUCTION OF COMBINED CONCRETE KERB AND CHANNEL *in situ*.

Kerbs may be formed with a suitable rectangular slot to allow surface-water to pass through into a gully, ditch or other surface water drain.

It is important to remember to lay vertical face-kerbs along through traffic lanes, about 2 ft. from the edge of the lane.

Treatment for Rural Roads.

It is not usual, nor is it necessary or desirable, to lay kerbs on roads in rural areas. The lip-type of edging to a gradient of about 1 in 3 is suitable for conditions in open country.

It is thus safe for vehicles to mount the margin in an emergency. Various types of sloped or lip kerbs, also parking kerbs and barrier kerbs are shown in Fig. 124.

Shoulders. These serve to increase the effective width of a road, and are useful to park disabled vehicles or for temporary stops. The width may be from about 4 ft. up to 10 ft., as conditions permit;

a width of 4 ft. will enable cars to rest without blocking the adjacent traffic lane; a greater width, however, is desirable.

Flagging. This method of footpath-surfacing is probably the most satisfactory from the point of view of permanence and of "reinstatement" after disturbance. Natural stone flags, as used in the past, have given place to artificial or concrete flags; these are cheaper and of better appearance; occasionally, however, it may be advisable to use a non-slip natural stone for the footpaths on steep gradients.

Generally artificial flags are rectangular and of a thickness of 2 or $2\frac{1}{2}$ in. and of sizes 3 ft. × 2 ft., 2 ft. 6 in. × 2 ft., or 2 ft. × 2 ft.

If flags are laid to provide a so-called bonding, they are laid as

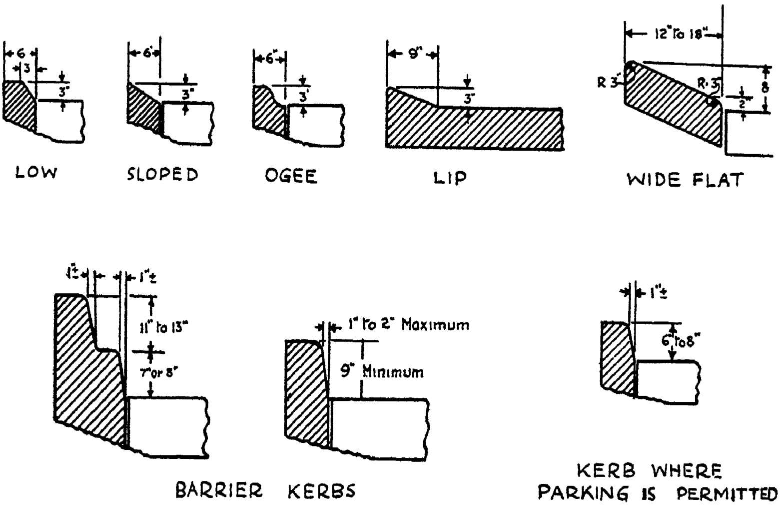


FIG. 124.—TYPES OF SLOPED OR LIP KERBS, PARKING AND BARRIER KERBS.

shown in Fig. 125*a*; this, however, is inconvenient and wasteful when they have to be taken up to deal with public-service mains. The bonding has no special merit, and it is probably a better plan to lay flags with the main joints running parallel to the kerb (Fig. 125*b*). Flagging should be laid with a crossfall of about 1 in 16, or thereabouts. Wherever possible step levels to premises should be fixed at a suitable height relative to the carriage-way.

Flags, Coloured and of Different Sizes.

The appearance of footpaths may be much improved by introducing coloured (usually red) flags in the ratio of about 1 to 3 or 4 of the natural concrete-coloured flags. The coloured flags are interspersed

with some irregularity so far as possible. In seaside towns red-coloured flags are often wholly used in promenade walks, to reduce reflective glare from the sun.

The appearance of flagged footpaths may be improved still further by the use of different colours and sizes of slabs; this gives a more interesting (and less monotonous) pattern and is more pleasing to the eye; yellows, reds, dark green, or black colours may be introduced as shown in Fig. 126.

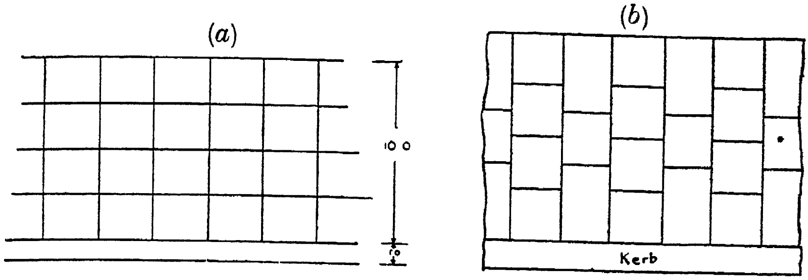


FIG. 125.—BOND OF ARTIFICIAL FLAGGING. STRAIGHT (a): BROKEN (b).

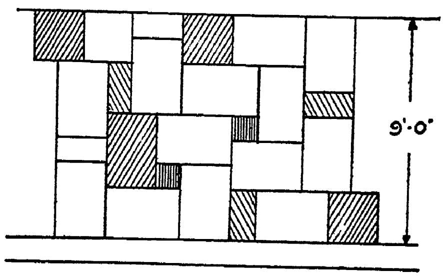


FIG. 126.—FLAGGING OF VARIED SIZES AND COLOURS.

"Crazy" flagging may also be used with advantage where an interesting appearance is desired, the broken flags must be carefully laid, and suitable cement or other mortar employed for bedding them.

Bedding of Flags.

All flags should be solidly bedded on a 3- or 4-in. layer of fine cinders or sand. Lime mortar may be used to assist in bedding the slabs, although this is not absolutely a necessity. The joints should be as close as possible and be filled with good-quality mortar.

Lifting Flags.

The close jointing of flags creates a difficulty in raising the first flag when mains operations are necessary. If some device were

available for lifting, less flags would be broken; occasional flags with small rings cast in manufacture would help; on the other hand, thin, ratchet-shaped hooks, inserted in the joints and turned, would enable a particular flag to be raised without risk of breakage.

Where footpaths are laid with *in situ* concrete it is advantageous to form joints by inserting paper at frequent intervals. This will facilitate "taking-up", and the joints will help to avoid irregular shrinkage cracks; also waterproof paper should be laid on the ground before placing the concrete.

Tarred Footpaths.

This type of construction is eminently suitable for footpaths on quiet or rural roads. It may consist of any one of the following :—

(*a*) Tarred limestone or slag.
(*b*) Cold asphalte.
(*c*) Tar sprayed and chipped surface, using hot tar or cold emulsion; two applications may be made if required.
(*d*) Soil stabilization with cold emulsion.

Gravel, shale, or cinder paths are often used in rural areas; opportunity should be taken to adopt methods of soil stabilization where practicable; finishing should be by light roller.

Circular Kerbs or Transitions.

It has been common practice in the past to lay the kerb between two roads at right angles with a "circular" turn.

If the radius is 30 ft. or thereabouts, this will be suitable for traffic; with a lesser radius, however—20 ft. or less—a compound curve should be introduced, the sharper curve being followed by the larger radius turn for left-turning traffic in each case.

The arrangement is shown in Fig. 127. This enables the inner rear wheel to clear the kerb when making a sharp turn; moreover, the vehicle turning is better able to keep clear of the centre of the main road into which it is moving.

Crossings over Footways.

Crossings over footways are necessary to avoid damage to the footpath construction.

They may be formed in concrete or tar macadam or asphalte, with or without kerbs to form a break or difference of level..

A "dished" crossing, either splayed or wide enough to facilitate turning, is usually quite satisfactory; the crossfall will quicken near the channel.

Where footpaths and roads are narrow, it is a good plan to ask for the gate and gate-posts to be set back behind the line of the street or front fence, this assists turning into the road more easily and is less liable to interfere with passing traffic.

Widths of Footpaths.

The question of defining widths of footpaths relative to the width of road should be treated without hard-and-fast rules.

Each road should be treated on its merits subject to a minimum width of 4 ft. 6 in being provided for at least one footpath. Regard

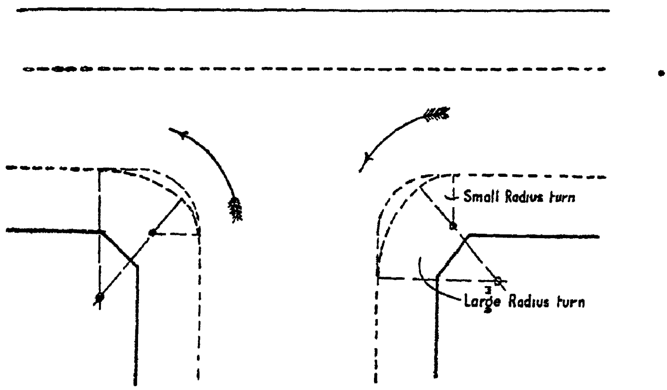


FIG. 127.—METHOD OF ARRANGING CIRCULAR KERBS AT INTERSECTIONS TO AVOID WHEEL-GRINDING.

should be paid to the character of the zones in the treatment of footpath design as follows :—

(*a*) Industrial; medium or narrow widths.
(*b*) Business or shopping; wide footpaths.
(*c*) Residential; various widths or margins as desired.
(*d*) Rural; unrestricted or undeveloped; narrow footpaths with margins.

It is a matter of some interest to consider making the footpath on one side of a road wider than on the other; one side is often the more popular with pedestrians. It will be found that footpaths on the north side (receiving more sun) are busier than those on the south side.

The Ministry of Local Government and Planning schedule of minimum widths for guidance in the planning of new streets in residential areas is reproduced on p. 99.

Elevated Footpaths.

Where levels or contours allow, one or both footpaths may be elevated with economy and advantage to the appearance of the road.

Such footpaths may be protected by (1) wide, sloping grass margins, (2) suitable but attractive walling or fencing, or (3) by double or treble steps of kerbs.

Existing trees and shrubs may be left standing and the footpath

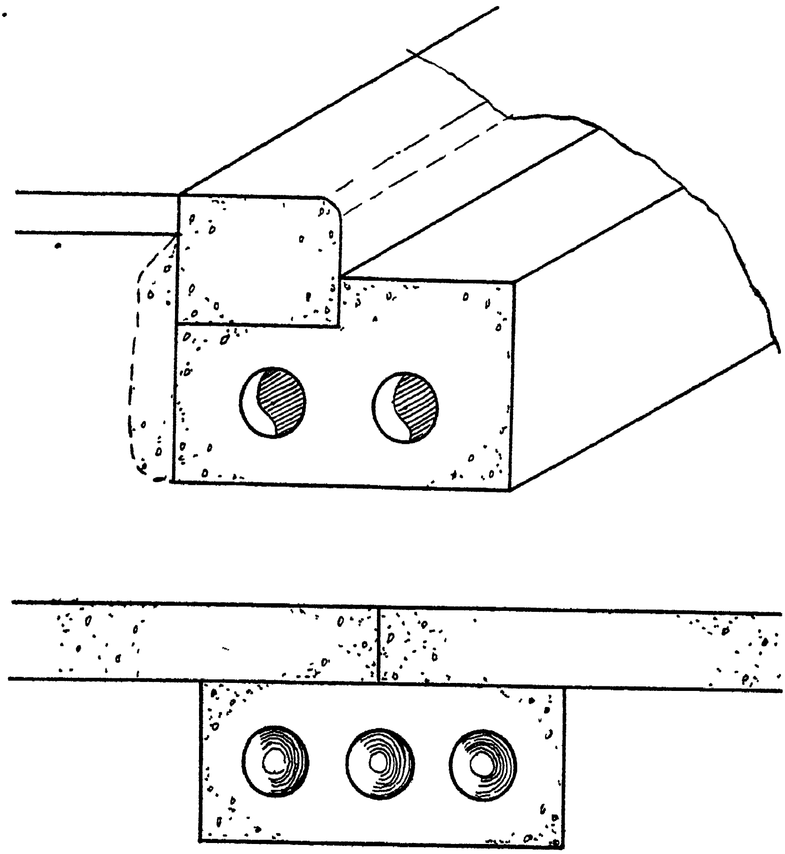


FIG. 128.—USE OF DUCT TUBES IN KERB AND CHANNELS FOR SURFACE WATER DRAINAGE.

constructed well beyond them, giving safety to the pedestrian and adding charm to the highway.

Duct Tubes in Kerbs and Channels.

The use of duct tubes in connection with the construction in *in situ* concrete may enable surface-water drainage to be effected without the laying of separate drainpipes. In Fig. 128 the pipes shown are 4-in. diameter; if not required for drainage they would be available for cables or small pipes.

CHAPTER XVIII

ROAD FACILITIES FOR CYCLISTS

It is generally accepted that the segregation of cyclists from the vehicular carriage-way is advantageous to the cyclist and to the motorist. moreover, the construction of separate cycle tracks will sometimes secure substantial economies in avoiding the necessity of widening the adjacent road.

A limited provision has already been provided on certain main roads in the form of 6-ft. or 9-ft. tracks on each side of the carriage-way; short lengths are ineffective, and every endeavour should be made to lay long lengths or to link up with cycle tracks on other roads.

Cycle tracks may be laid in different ways as follows :—

1. Cycle tracks on either side of a single or dual carriage-way.
2. Parallel service roads to carry cyclists instead of special tracks.
3. Cycle track on one side of the road only (Footpath might serve as cycle path in quiet rural areas, as is done in Holland and elsewhere.)
4. Special cycle roads independently of main roads (e g. as in Denmark and elsewhere).
5. Use of narrow country lanes where speeds of not more than 20 m.p.h. would be reasonable for motor vehicles: cyclists should enjoy safety on these roads.

Dual Cycle Tracks.

In case (1) and (2) the cyclist follows the flow of motor traffic in each direction, although if the track is 9 ft. or more (in 3-ft. units), it may be used for cycles either way if need be: this applies more easily to the service road, since this is wider.

Cycle tracks may be laid in $4\frac{1}{2}$-in. concrete paving or asphaltic or tar macadam: they should be drained either by camber or side fall and small kerbs or level edgings may be used, in this connection: a safer condition occurs if the track is level with grass margin or is raised above it and kerbs are omitted. Gullies or draining-off points should be clear of the track if possible, and easy facilities should be afforded for clearing stoppages.

Good maintenance is essential if cyclists are to be encouraged to use the tracks. The frequency of the gullies will depend on the longitudinal gradients.

It is a good plan to plant a line of trees or hedges between the cycle track and the carriage-way : a margin of reasonable width is necessary to provide for this; hedges will help to break the wind and make riding more comfortable for cyclists. Careful attention should be given to the levels of the tracks when these cross at road junctions or entrances to garages.

Single Cycle Track.

The advisability of providing one cycle track on one side only of a main road will depend on local conditions : for example, if in the vicinity of an industrial area the cycle traffic may be all one way in the morning and the opposite way in the evening.

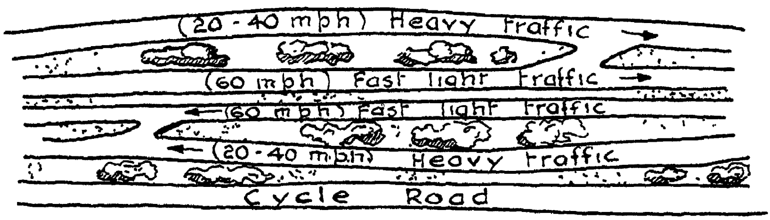


FIG. 129.—DIAGRAM SHOWING SEPARATE ROADS FOR LIGHT AND HEAVY TRAFFIC AND ONE CYCLE TRACK.

In the diagram, Fig. 129, showing separate roads for fast, light, and for heavy traffic, one cycle track (or road) only is provided.

Special Cycle Roads.

There is a good case for constructing special cycle roads free from intersection by motor traffic : roads leading to beauty spots or to resorts on the coast would attract cyclists, and naturally such roads would be free from accidents with motor vehicles.

Certain field footpaths or "footpaths only" in urban areas might well provide a cycle path alongside as a convenience to the cyclist and a benefit to the pedestrian. Studs are useful to separate the two.

Linking up Country Lanes.

Many narrow country roads are unsuitable for any speed above 20 m.p.h., and it is absurd to allow unrestricted speed on such roads; it would be little hardship to impose a 15 or 20 m.p h. speed limit on roads of this kind in order to make them safe for cyclists. A few new connecting cycle roads (with footpaths, also) would enable convenient and attractive routes to be planned : cycle tracks in busy main roads should also be linked up if possible with cycle tracks and

narrow lanes suitable for low-speed traffic on other roads, as shown in Fig. 130.

The Trunk Roads Act, 1945.

This Act affords an excellent opportunity to build cycle roads and footpaths which need not be adjacent to the carriage-way: it is a pity that the limit of 220 ft for this purpose is not greater, or that greater encouragement to take cyclists and pedestrians even farther away is not provided in the Act.

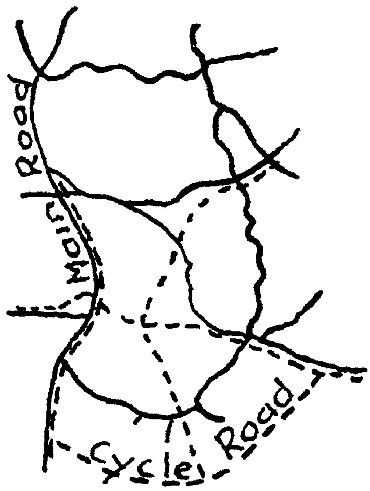


FIG 130.—SUGGESTION FOR LINKING UP COUNTRY LANES BY CYCLE TRACKS.

In spite of this, however, there is a great opportunity to plan attractively for segregation and safety in the best possible manner.

Cycle Tracks and Halt Signs.

It is important that cycle tracks alongside a main-road carriage-way should be protected from side-road traffic: this can be done by ensuring good visibility at the corners or, better still, by fixing "Halt" signs (Fig. 161).

Subways for Cyclists and Pedestrians.

Subways are suggested in connection with fly-over junctions to secure the continuous passage of pedestrians and cyclists by passing beneath the paths of the road traffic; there are many cases where

similar culverts would be useful beneath railways as opposed to footbridges.

The following dimensions are suggested as a minimum by the Ministry of Transport :—

Type of subway	Clear headroom.	Clear width.
Pedestrian	7 ft.	7 ft. 6 in.
Cycle . one-way	7 ft. 6 in.	10 ft. 6 in.
Cycle two-way	,,	15 ft. 6 in.
Combined cycle and pedestrian subway, one-way	,,	16 ft. 6 in (6 ft. 6 in footway)
Combined cycle and pedestrian subway, two-way	,,	21 ft. 6 in. (6 ft 6 in footway)

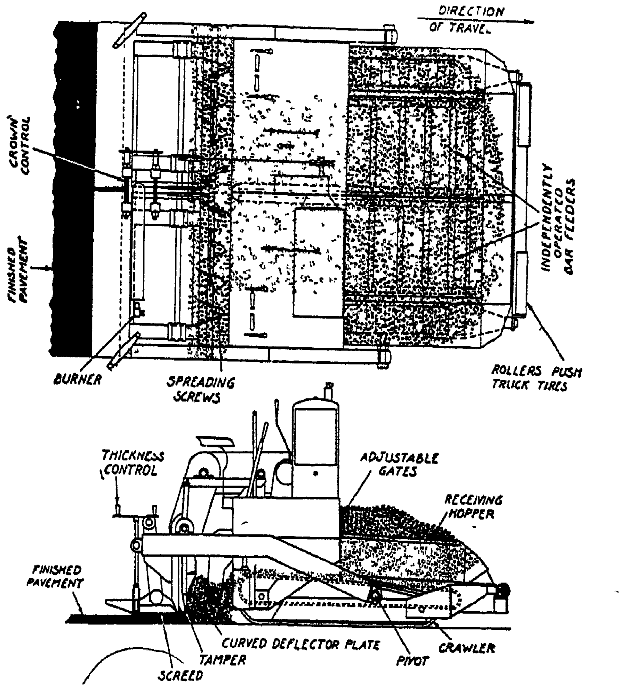
The maximum gradient for ramps for pedestrian subways should be 1 in 10 and for cycle ramps should be 1 in 20 for up- and 1 in 15 for down-gradients.

CHAPTER XIX

CONSTRUCTION EQUIPMENT AND PLANT

IN order to carry out roadworks at minimum cost, it is essential that the best type of plant and machinery available should be employed for the particular work in hand.

Naturally large schemes offer the best scope for the employment of machinery; it is necessary to have an efficient organization of the



[Courtesy Messrs Jack Olding, Ltd.

FIG. 131.—BARBER GREENE TAMPING, LEVELLING AND FINISHING MACHINE. (PLAN AND SECTION.)

whole of the plant and materials required in order to gain the fullest advantages from the use of such machinery.

New plant is being designed and manufactured from time to time and improvements are being made to existing plant; all these have the purpose of speeding up the particular job, reducing the cost, and saving man-power.

As mentioned elsewhere, perhaps one of the most important machines which has been developed to a pitch of high efficiency since the war is the Barber Greene Tamping Levelling Finisher, shown in Fig. 131.

A brief list of some of the more important types of machinery for the different kinds of road and road-work is given in the following schedule

1. *Earth Moving and Soil Stabilization.*

Excavators
- Skimmer bucket.
- Face-shovel.
- Drag-line.

Trench excavators.
Scrapers.
- 4-wheeled and 2-wheeled rotary scraper.

Bulldozers.
- Angle-dozer.

Rooters (heavy scarifier).
Compressors, including all equipment—e g., pumps.
Dumpers.
Blade grader.

2. *Bituminous Roads.*

Pressure distributors (liquid) or sprayers.
"Mix in Place."
- Disc, spike harrows, drags, re-tread mixers.
- Graders.
- Spike-tooth and paddle mixers.

Travelling mixing plants (Barber Greene).
Stationary plants, including driers, crushers, elevators, etc.
Driers and heaters (oil-burning).
Screens, rotary and vibrating.
Spreader box or gritter.
Broom-drag.
Mechanical spreaders, various types.
Self-propelled Rollers, three-wheel and tandem types (3–20 tons weight).

3. *Concrete Roads.*

Sub-grader, hauled or self-propelled.
Standard paving mixer.
Side forms.
Power-driven finishing machine.
Vibrators.
Mechanical spreader.

Machine for making dummy joints.
Power-driven longitudinal float.
Water and membrane sprayers.
Concrete mixers (various types including transit mixers)

4. *Maintenance (General).*

Light lorries and vans and trailers.
Heavy lorries.
Power brooms.
Compressors.
Bituminous distributors.
Power and towed graders.
Tank-car heaters.
Bib-kettles.
Loaders.
Crushing plant.
Snow-ploughs.
Rollers.
Power shovels or cranes
Spreaders.
Storage tanks.
Tractors (caterpillar or wheel).
Traffic-line markers
Welding machines.
Grass and margin-cutters.

GENERAL MAINTENANCE—CLEANSING AND TAR-SPRAYING

THE efficient and economical maintenance of roads and footways is an essential feature of road engineering; "good maintenance pays dividends" is a good slogan.

It may be that light construction with relatively high maintenance costs may be cheaper than a more expensive road carrying heavy annual loan charges.

Maintenance may be classified under the following headings:—

(*a*) The road surface and footways.
(*b*) Drainage, gullies, ditches, drains, and culverts.
(*c*) Cleansing—road-sweeping.
(*d*) Shoulders or margins—"siding".
(*e*) Snow and ice control.
(*f*) Traffic-control service; signals, guard-rails, signs, etc.
(*g*) Bridges, road surface, and the structure.

Maintaining the Road Surfaces.

This will necessitate the following operations:—

(i) Repairing small surface failures by "patching".
(ii) Repairing large areas by scarifying, re-shaping, and re-treating, using new materials where necessary.
(iii) Dragging and blading gravel or similar surfaces.
(iv) Stabilizing soil aggregate surfaces with bituminous or chloride treatment.
(v) Inspecting and adjusting projecting or defective manhole covers.
(vi) Bituminous or tar-spraying to seal against water penetration and to renew the binder.
(vii) Cleaning and filling joints and cracks in concrete and sett paved roads: large areas of failure to be replaced with reinforced concrete.
(viii) Non-skid treatment.

Drainage.

This includes:—

1. Emptying gullies.
2. Cleaning surface-water drains, culverts and ditches.

(It is worth noting here that on the German autobahn there are no gullies or surface water-drains.)

Cleansing.

This requires to be carried out regularly in built-up areas and less frequently in rural areas. In the former case the mechanical sweeper is usually employed for main and through roads: some hand-sweeping may be necessary to deal with footways, etc.

Shoulders and Margins—Siding.

This involves :—

1. Mowing grass margins and shoulders to assist drainage.
2. Maintaining slope-away from pavement on open roads.
3. Preventing erosion of slopes and embankments; planting shrubs and turf as a prevention; pruning trees
4. Cutting hedges or long grass to maintain sight distances; removing dangerous or fallen trees.

Snow and Ice Control.

1. Snow-ploughs should be available for winter season for removal of snow.
2. Gritting or salting ice-bound surfaces.
3. Keeping drain outlets and channels clear during the thawing period.

Traffic-control Areas.

This involves :—

1. Repairing, painting, and preserving all warning signs, guard-rails.
2. Inspecting and checking traffic signals periodically.

Bridge Maintenance.

This requires the following services :—

1. Maintenance of the superstructure, including painting.
2. The road surface must be maintained to a very high standard.
3. Maintenance and inspection of the substructure, including protection from scour and keeping the waterway clear.

TAR-SPRAYING

As a feature of road maintenance, tar-spraying or surface dressing is of great importance: it is comparatively economical, and with it a good road surface can be preserved for many years.

Normally an application should last about three years: it is

desirable that the accumulated thickness of tar and chippings should be limited, otherwise it will creep or work up into corrugations. A key plan and log should be kept showing the dates when and how the various sections were treated and the prevailing weather conditions

The Road Research laboratory of the Department of Scientific and Industrial Research has issued a useful brochure on "Surface Dressing", some details of which are given below. All surfaces should be levelled up by patching depressions with fine tarmac or tar and chippings.

Treatment of Tar or Bitumen Surfacings.

The tar should conform to Specification B S. 76, 1943.

The viscosity will vary according to the seasons of the year.

Months	Main roads.		Other roads.	
	E.V.T. in ° C.	Viscosity at 30° C. in Sec. B R.T A.	E V.T. in ° C.	Viscosity at 30° C. in Sec. B.R.T.A.
April, October .	32–35	70–120	28–31	35–60
May, September .	33–36	80–150	30–32	50–70
June, July, August	35–38	120–200	32–34	70–100

All loose material should be brushed off before spraying operations; spraying should be done preferably by a mechanical tank-sprayer, which should be checked for volume, temperature, and uniformity of delivery: the temperature of the tar should be between 220° F. and 280° F. (with open tar-boilers the temperature should be between 180° F. and 240° F. according to viscosity).

Rate of Spread.

At the beginning of the operation the covering rate of the tar should be checked over a sufficient area—with hand-sprayers a careful check-up of volume used against a measured area should be made.

The rate will depend to a large extent on the kind of chippings used, as shown in the graph (Fig. 132).

The rate will depend on whether the road surface to be treated is "hungry for the tar or not"; a less rate would be applied for a well-laid road rich in binder.

The chippings should be dry to ensure the best results: if damp, the road should be kept free from traffic until they have dried with adhesion to the tar. It is a good plan to keep traffic off a newly sprayed surface for several hours to allow for a complete "set";

and perhaps re-rolling will improve the finish. All this may slow down the operation if the road has to be kept open half-width, but the extra cost involved may be well worth while

Testing of Materials.

The tar-binder and chippings should be tested at the commencement of the work and during its progress in accordance with standard methods.

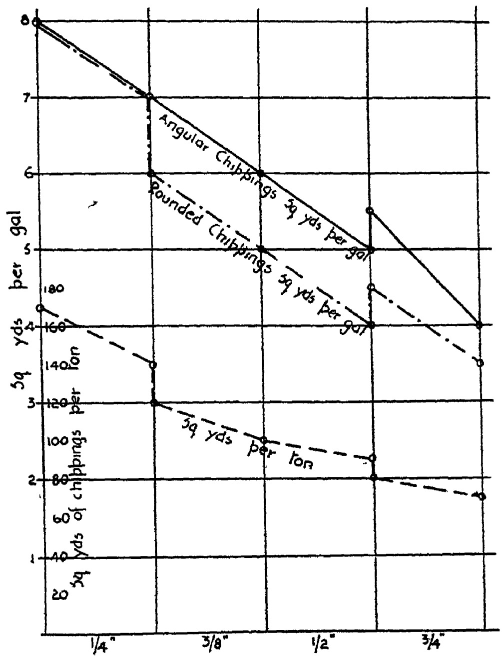


FIG. 132.—GRAPH SHOWING THE RATE OF SPREAD OF CHIPPINGS PER GALLON OF TAR.

The rate of spread of chippings will vary with the size, as shown in Fig. 132. $\frac{3}{4}$-in. chippings will spread at the rate of 70–80 sq. yd. per ton, while $\frac{1}{4}$-in. chippings will cover 140–170 sq. yd. per ton.

Tar Treatment of Water-bound Macadam.

Owing to the "open" nature of water-bound macadam it is necessary to use a lower viscosity tar spread at a rate of $3\frac{1}{2}$ to 4 sq. yd. to the gallon (e.g. 30–40 sec. at 30° C. in the summer, 20–30 sec. in the winter), and the chippings should not exceed $\frac{3}{8}$-in. gauge.

Surface Dressing of Concrete Paving.

A well-laid concrete road should not require tar-spraying. Where it is tried out in order to give a smoother surface or to prevent further deterioration, great care should be taken to level up any inequalities prior to spreading, also the surface should be well brushed.

Two applications are necessary to secure good results, the second treatment being applied after the first has been compacted by traffic: the chippings should be $\frac{1}{4}$-in. or $\frac{3}{8}$-in. for the first and $\frac{1}{2}$-in. for the second dressing.

Cement-bound Macadam.

Cement-bound macadam offers a better key for tar dressing, and good results may often be obtained from one dressing.

Location of Depots.

In order to carry out maintenance work satisfactorily, it is necessary to provide depots and workshops where plant and materials may be kept in readiness for daily use. Their location should be fairly central for the area of operations to be covered. Each depot should be in the hands of well-trained men who are able to service all vehicles and plant and who can maintain an adequate store of spares.

Ample garage accommodation for all vehicles and plant is essential for efficient plant maintenance.

CHAPTER XXI

UNDERGROUND WORK, REINSTATEMENT OF PAVING, AND PATCHING

THE question of laying or renewing underground mains in the public highway has been until recently a fairly simple process The rapid increase towards perfection of modern roads has been accompanied by an equally rapid development and extension of underground mains of various kinds, especially in connection with the use of electricity. The principal mains which have to be considered in connection with highway work are :—

1. Sewers.
2. Surface and foul water drains.
3. Water or hydraulic power mains.
4. Gas mains.
5. G.P O. telephones.
6. Electricity mains.

All these varying classes of mains have their individual systems, each with innumerable connections to property.

It is possible that there will be a further development of underground work in large cities, as, for instance, along the lines of a parcel-delivery system.

Where very large sewers or subways have been laid, the problem of reinstatement is not of so much importance, because these give access throughout.

The modern road, whether it be of a tar or bituminous nature, or concrete foundations or surface, should not be interfered with except in very urgent circumstances. The cost of providing a suitable road crust for modern traffic is so very heavy that no authority can afford to have it disturbed whilst the surface is in good condition. Once disturbance has been allowed to take place it is exceedingly difficult to bring the road to its former condition. Cross trenches are particularly objectionable, as they set up that vibration which produces corrugation.

The Public Utilities Street Works Act, 1950.

The Public Utilities Street Works Act, 1950 has been introduced to avoid unnecessary and frequent disturbances of the highway.

This Act was brought in to provide a " Street Works code of Statutory Powers for Mains Authorities or Undertakers "; it came into operation on April 26th, 1951, and supersedes all other general

and special codes; it governs the relationship between highway authorities and the various undertakers and between the undertakers themselves.

Major works must not be commenced before plans and sections or notice (lasting two months) is given to all Authorities concerned for agreement between them as to the work.

Emergency works are dealt with separately; if dispute arises, the matter is referred to arbitration

The Act contains provision relating to the following :—

(*a*) Limitation of rights against Government oil pipe-lines.
(*b*) Access to the site.
(*c*) Scope of arbitrator's powers.
(*d*) Conditions relating to disturbance and reinstatement
(*e*) Supervision payments by the undertakers.
(*f*). Safety measures, such as fencing, lighting, and watching.
(*g*) Right of Authorities to do work themselves where interference with their mains or apparatus demands it.
(*h*) Conditions relating to transport and sewer authorities where additional strengthening works are necessary.
(*i*) Protection for the operation of rail- and water-borne traffic.

The Act deals with all aspects of street disturbances and reinstatement; it seems somewhat complicated, but it is a complicated subject, and it will take some time for the various powers conferred by the Act to work smoothly.

It is proposed here to indicate some of the more important aspects of reinstatement works.

The Importance of Depth.

The depth at which the underground services are laid affects the disturbance of pavements to a considerable extent. In the case of the shallower mains it is imperative to obtain access from the surface for the whole length of the main, but in the case of deeper mains, such as sewers and certain water-mains, the breaking-up of the road surface may, in many instances, be avoided by tunnel-work and occasional sinkings in various places along the route. Water-mains are usually laid moderately shallow, as also are gas-mains, electricity, and telephone cables; especially is this so where the mains can be placed under the footpath, in which case the highway engineer is not seriously concerned, except in so far as crowding the space underneath the footpath may drive the future pipe-lines into the carriageway. It is clearly advisable to have all these mains under the footpath if possible, so that access may be obtained in an inexpensive manner and without interference to traffic; the rights of pedestrians should also be considered.

SUBWAYS FOR UNDERGROUND WORK

In town areas the objections to disturbance of carriage-way and footpath are particularly serious, and it is necessary to devise some method of minimizing the inconvenience to pedestrians and traffic as much as possible The most important proposal which has yet been made towards the solution of this problem is the provision of subways to contain gas, water, electricity, and P O. mains, as shown in Fig. 133. This would enable access to be obtained throughout the whole length by entering the subway at manhole stations. In the centre of the city such subways would permit of renewals, repairs, connections, and the fullest possible access and inspection throughout the whole length, without any interference or inconvenience on the surface.

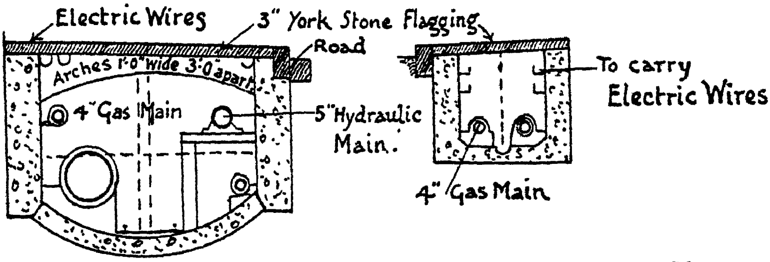


FIG. 133.—SHALLOW SUBWAYS FOR GAS, WATER AND OTHER MAINS.

In order to eliminate the risk of explosion due to gas leakage, adequate ventilation, as in the case of sewers, is essential.

The initial cost of the subway should be borne by each of the departments concerned, and whilst this expenditure may appear to be greater than the cost of laying the same mains in the ground under the footpath, the subsequent saving will more than repay the cost incurred in the construction of the subway. The dimensions of the subway should be sufficient to contain several lines of electricity supply cables of various pressures; Post Office cables; and gas- and water-mains up to 12-in. diameter. Space should also be left to allow sufficient clearance for a man to pass along easily.

The provision of a subway in town areas would, among its other advantages, largely prevent the external corrosion of the pipes or mains.

Manhole Shafts.

These should be provided at convenient intervals and at important junctions of mains, so that access for pipes and other materials may be obtained without having to travel any great length of the sub-

way. These access shafts are comparatively inexpensive—es pecially when constructed on the principle of the concrete sla chamber shown in Fig. 134—if they can be arranged to occur o the footpath, and a light manhole cover utilized. Manhole cover in the carriage-way are most objectionable, they require to be of very heavy type to resist impacts from road traffic, and almost in variably they work loose or develop some play which may rende

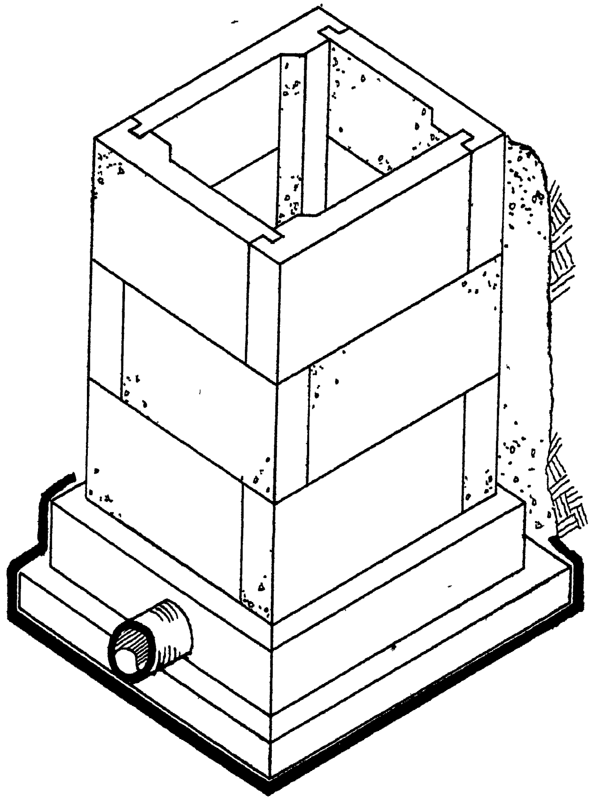


FIG 134.—CONCRETE SLAB MANHOLE CHAMBER.

them dangerous and unsafe. Moreover, the existence of a rigid-frame manhole cover in a tar or bituminous road-crust may become the starting-point for wave formation. Various methods have been devised for eliminating this latter difficulty; sometimes setts are paved round the cover in order to prevent the formation of depressions which often result at the junction of an iron cover with a yielding tarmac road surface.

In the case of iron covers in a road surface paved with granite setts or asphalte on concrete or concrete alone, this difficulty does not arise in the same degree, although the cover itself will be liable

to develop play. In any event manhole covers should be avoided on the carriage-way (if this is possible) for sewer work where access is required only infrequently. It would be more economical to have the access cover beneath the road surface in such a position that it could readily be located when required A submerged manhole shaft could be covered with a blank concrete slab, and this method would eliminate the wear which occurs round exposed iron covers. Special footpath markers could be utilized for denoting the exact position of these submerged shafts.

A large number of manhole covers have been designed with a view to eliminating the tendency to rock under traffic.

Side-chambers are very often useful in obtaining access to subways, sewers, or other culverts, where it is difficult, on account of traffic, to enter them from the top, but they are necessarily expensive.

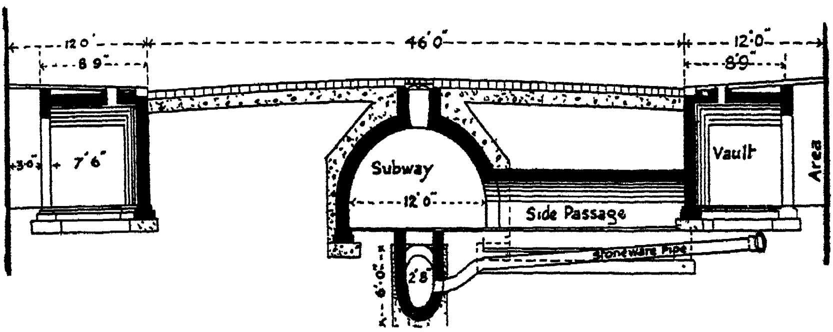


FIG. 135.—SECTION OF SUBWAY, VICTORIA EMBANKMENT, LONDON.

Mains on Footpaths in Urban Areas.

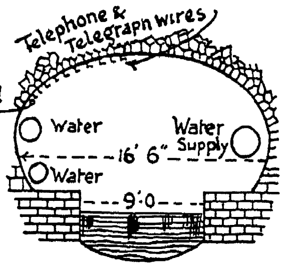
In the case of suburban areas where wide footpaths are provided on each side of the road, the mains can be laid fairly inexpensively at shallow depths under the footway.

The tendency of housing development to-day is to provide wider footpaths and somewhat narrower carriage-ways than hitherto, the former allowing for a grass or gravel margin. This feature is of considerable value to the mains authorities, because the disturbance and reinstatement of these margins is a comparatively simple matter.

In residential areas fire hydrants may be fixed on the footpaths, providing that some concrete or sett paving is laid around to take the water to a channel in the carriage-way. The sewers may be laid away from the carriage-way in cases of this kind, although cross drains for gullies will be required, as is the case when the sewer passes down the centre of the road; it is particularly easy to accomplish this on some of the lesser or cul-de-sac roads on housing schemes. Where cross-fall from one side to the other is employed, and gullies

on the lower side only are provided, there need be no cross drains sewer whatever in the carriage-way.

Subways have been constructed in the past, notably in Lond (Fig. 135), Nottingham, and Paris. Those in the City of Lond are probably the most complete of their kind, but from their exte and special circumstances, caused by the varying levels of intersecti streets, their construction was very costly Accommodation f



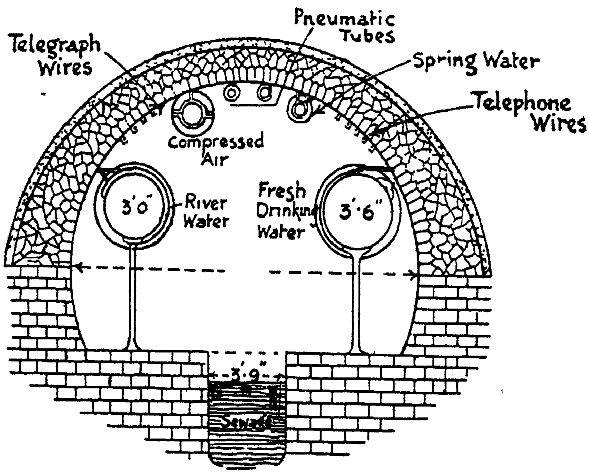


FIG. 136.—SECTION OF SUBWAYS, PARIS.

future extensions of pipes and mains was provided, and also con venient access. The subways are lighted by gratings in the footway fitted with glass lenses placed at intervals of 4 ft, and in addition t this, artificial light is provided. Water pipes are supported by iro chains; the gas, electricity, and other pipes are carried on wall brackets; and ample space round each of the pipes is allowed fo access purposes. The water-mains are provided at intervals wit stop-cocks, air valves, and emptying cocks which discharge into th sewers; and also with hydrants for the purpose of washing out th subways. The temperature obtaining in subways is of special im

portance during cold weather. The minimum temperature of the average subway will be above freezing-point.

The Nottingham subways are ventilated by means of gratings at the surface level of the street placed about 48 ft. apart, also by three side entrances and by open gratings in a refuge at the lower end of the street. Brackets are fixed in the subway for carrying pipes, as in the case of London. An extensive system of subways exists in the City of Paris. Fig. 136 shows the construction of a main sewer and subway in the Boulevard Sebastopol. This tunnel is 11 ft high and

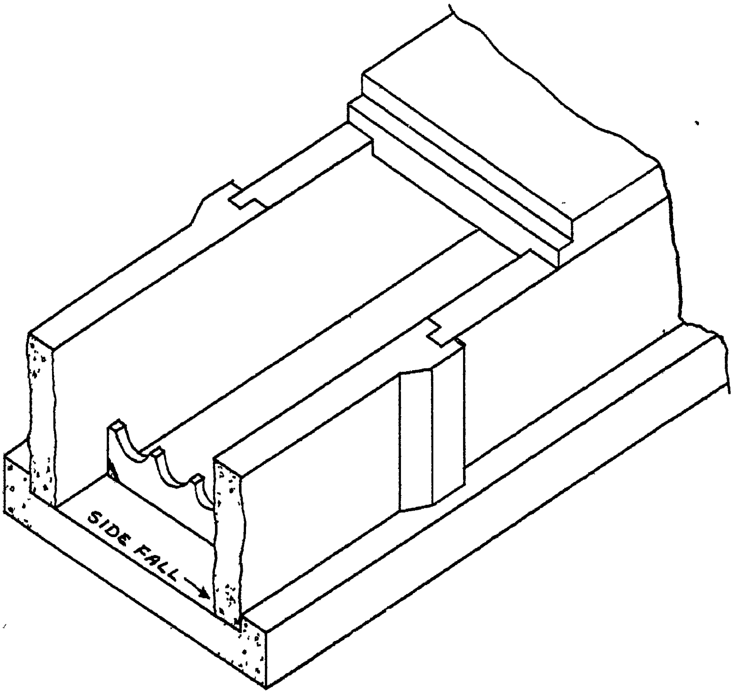


FIG. 137.—DISTRICT HEATING SUBWAY AT URMSTON (LANCS.)

16 ft. wide; two large catchpits are constructed for the collection of boulders, sand, stones, and other rubbish which have been washed down the numerous channels that empty themselves into the collector and settle into these pits. The sewage runs in the centre or side channel 5 ft. deep and 3–4 ft. wide. Pipes are provided for carrying fresh water and river-water supplies; also electricity and other cables, and pneumatic tubes.

Subway for District Heating Mains.

An additional service which may develop in this country is that of district heating where mains are required if possible to be laid in the

footpath; in many cases the ducts are laid in new housing estate and it is easy to adapt the top slab of the square culvert as part (the footpath—this gives a credit to the service, equivalent to th cost of flagging.

The system may vary between a two-pipe, three-pipe, and a 4 pipe, and this affects the width of the duct. Fig. 137 shows a duc for a four-pipe system which the Author designed for use in footpath of private streets in Urmston.

It is essential that the culvert should be connected to gullies c surface-water drains at intervals so that any water leaking in, eithe from the pipes or from outside, can drain away.

If a cross fall and channel at one side is formed on the floor of th duct and there is also a little longitudinal gradient, water will ge away easily.

The top slabs are easily moved for access purposes.

Thrust Borer.

This apparatus enables horizontal borings to be made withou disturbance of the road surface, excepting, of course, the sinking fo the starting point. It is possible to make borings 50 yd. in length from one setting and to thread in 6-in. earthenware pipes; in th case of small-diameter pipes the process, in suitable ground, is ver rapid and economical. It is very convenient to use for passing unde tramway tracks and busy thoroughfares where traffic cannot easily be interrupted. It is necessary to make careful enquiries regarding all existing mains before using this apparatus, in order that the bore will not foul them in the process of boring.

Use of Duct Tubing.

This process concerns the formation of pipe-holes or tubes in concrete laid *in situ*. An inflated rubber tube is laid at the required level, concrete being poured around it; after setting, the tube is deflated and withdrawn. It would seem possible to form these smal pipe-conduits in the concrete channels or in concrete below the kerb also ductings can be laid across a concrete carriage-way; examples of this are shown in Fig. 128. These ducts could be provided, at little cost, well ahead of possible requirements for lighting or G.P.O cables, for example.

Reinstatement of Bituminous or Tarred Macadam

In the absence of subways for mains, and with insufficient foot-path space to eliminate the necessity for laying underground mains in the carriage-way, the reinstatement of road surfaces after distur-

bances for repairs or renewals of the mains requires careful and judicious treatment by the road engineer. If possible the road engineer should place an inspector on the work to supervise, on his behalf, the reinstatement of the disturbed area and to prevent possible interference with other mains Where this is not done the workmen employed on excavation and filling will naturally become careless and haphazard in their methods, which will result in increased expenditure for the authorities.

It is a sound proposition to have the filled-in material thoroughly well watered and punned as the filling-in of the trench proceeds. Another point which occasionally upsets the calculations of the mains authorities is the subsidence of the paving immediately adjoining the trench. This is what the road engineer may expect to occur, and the amount of the subsidence will depend on the nature of the ground, depth of the trench, and the time that the trench is open; a little cement mixed into the filling will help to prevent settlement.

Temporary reinstatement may be done by filling in the road material above the level of the road, to allow for settlement. As regards cross trenches, this is not very satisfactory, as the material works itself into a ridge and causes serious impact from traffic upon the untouched road immediately adjoining the trench. So far as longitudinal trenches are concerned, constant inspection and raising of the surface may be necessary in order to maintain the road in a condition of safety.

Reinstatement of Sett Paving.

With regard to the reinstatement of sett paving, on a non-rigid foundation, similar precautions are necessary; the paving should be laid "dry"—i.e. without grouting of the joints—in order that it may be raised easily after settlement has taken place. Cinders are usually applied temporarily both for the filling of the joints and the covering of the reinstated section. When settlement has practically ceased, the setts can be permanently reinstated with a proper pitch grouting and chippings.

Reinstatement of Concrete Slab Paving or Foundation.

The reinstatement of either a concrete foundation or surface is usually a matter of some anxiety for the engineer. Normally the concrete cannot immediately be reinstated, owing to the slow process of settlement, and the edges of the existing concrete are in danger of breaking off owing to the partial subsidence of the sides of the trench. Secondly, when the reinstatement of the concrete is effected there is a possibility that some further settlement underneath the slab may occur, and so cause the concrete to crack. Some means, therefore, must be found to circumvent these difficulties. Perhaps

the safest plan is to distribute the weight over the undisturbed foundation by reinforcing the concrete with a suitable fabric and bridging the trench by hacking away the sides; alternatively, cement may be added to the filling.

With a deep trench this might necessitate reinstatement of a very wide span, and this would obviously be a very expensive operation. With a shallow trench permanent reinstatement can be performed within a very short time after the filling; if weak or rough concrete is placed in the trench as filling, the road surface may be relaid almost immediately.

As an instance of this treatment, a case may be cited where the only position possible for a new high-tension cable was beneath the channel of a concrete road, the trench being 3 ft wide and about 4 ft. deep to the top of the cables. Ordinary filling would have left the subgrade beneath the adjoining slab unsupported, with the inevitable result that serious cracking would have ensued. The contractor was required to fill in the trench with a 9 : 1 mixture of clinker concrete to within 4 in. of the surface. Upon this filling rapid-hardening granolithic concrete, with fabric reinforcement, was laid by the highway authorities to the cost of the contractor (Fig. 138). Thus the road was actually stronger than before disturbance.

Some irregularity of the joint with the existing concrete is an advantage, as this may be arranged to give a greater span in some parts than in others. Where the original concrete slab has been reinforced it may be possible to take advantage of the projections of the steel in order to link up with the new reinforcement.

Another method of reinstating concrete is to lay it some 2 or 3 in. thicker than the original slab, with the additional thickness passing under the thinner slab, thus giving a greater bearing area and support to the undisturbed concrete. The sides of the old concrete may be stepped or sloped to give a key for the new slab (Fig. 138).

The object of this greater area and thickness is partly to give greater mass or moment of inertia to resist disturbance or movement due to traffic loads, and partly to afford support to the adjacent and original slab. The author has found this method entirely successful in practice.

The use of square-mesh reinforcement is often justified in repairs of this kind where additional strength and rigidity is required. Some years ago, the author laid a concrete road, having a hairpin bend, carrying heavy traffic under the worst conditions, with this 4-in. square-mesh reinforcement in the surface; it is now taking the wear which would otherwise be borne by the concrete wearing course, and which would have failed long since owing to the twisting and grinding action of the wheels of heavy vehicles on sharp curves. Fig. 139.

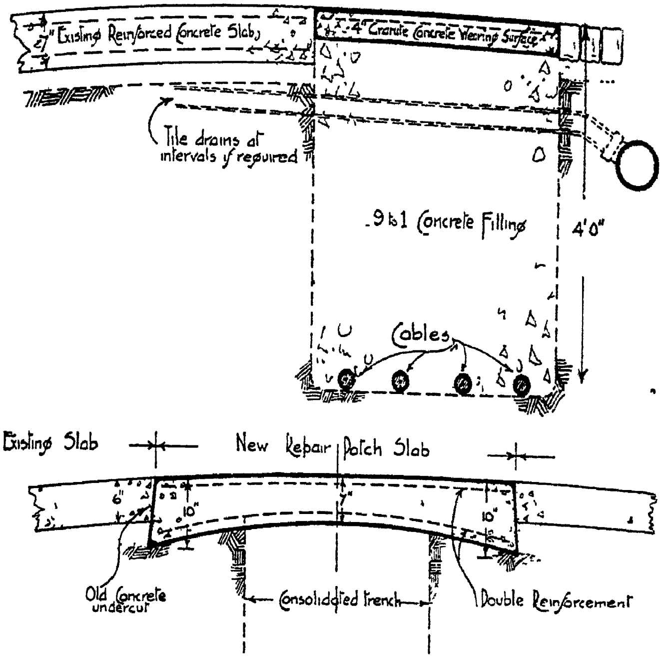


FIG. 138.—METHOD OF REINSTATEMENT FOR MAINS DISTURBANCE AT CHANNEL AND AT CENTRE OF SLAB

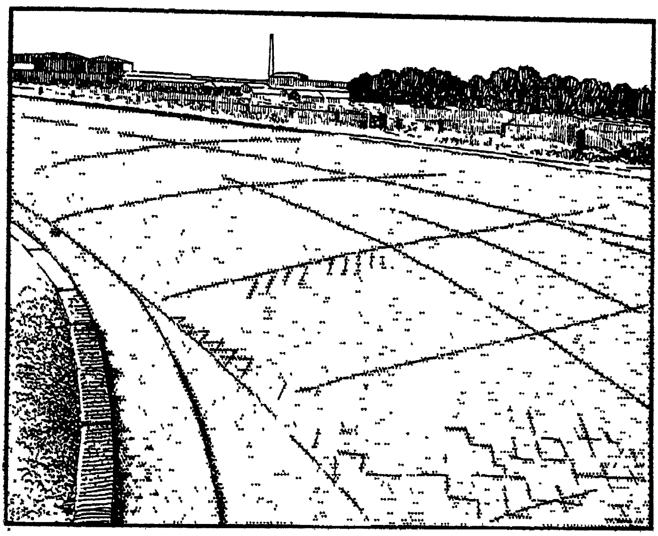


FIG. 139.—SQUARE-MESH REINFORCEMENT OF CONCRETE AT HAIRPIN BEND, TRAFFORD PARK, MANCHESTER. CONDITION SATISFACTORY AFTER 25 YEARS.

An interesting test was made in London, in connection with the gas companies' objection to reinforced concrete, to determine the relative time required to break through a 6-in. reinforced concrete slab and a 12-in. plain slab under exactly similar conditions. The time taken for the unreinforced slab was much greater than that taken for the 6-in reinforced slab.

As a precaution against the damage from the bursting of a water main below concrete, iron tubes may be placed vertically above it at intervals in the slab to allow the water to rise without lifting the pavement.

General Patching.

If the foundation of a road is weak, or of unequal strength, the very best quality of surfacing material will also fail.

The sub-structure of a road may fail for a variety of reasons :—

(*a*) The subsoil may have a low-bearing value.
(*b*) A high subsoil water-level may reduce the bearing power of the base, or cause it to fluctuate according to seasons.
(*c*) On roads of less width than 25 ft. the edges or channels may fail, owing to insufficient support from the subsoil under the weight of traffic.
(*d*) Failure may occur owing to deficient subsoil drainage.

Under any of these conditions, failure of the road-slab may be expected, and the engineer will be called upon to effect the necessary repair. Similarly, he will be required to carry out reinstatement of roads broken into by mains authorities.

Any road may be "patched" as an emergency measure with tarmac chippings or "topping" where potholes or depressions occur. Such defects should be brushed and cleaned out prior to placing the material; if possible a cold emulsion should be painted on the defective surface before applying the tarmac; also the surface surrounding the repair may be treated with cold spray and chippings as a precaution against further deterioration. The patch, of diamond shape if possible, should be well tamped or rolled by hand or steam roller to a level slightly above that of the existing road.

Small "patches" are undesirable, as they lead to vibration and corrugation; repair by means of cold emulsion and chippings for small or shallow depressions is preferable to patching with tarmac.

Patching of larger areas finished by steam-rolling is more successful, and in the ultimate results, more economical than the hand-patching of numerous small areas.

Patching Slightly Worn Concrete and Asphalte.

When a concrete surface has failed to a depth of about ½ in by reason of defective materials or carelessness in placing, the remainder of the slab may be sufficient to carry the traffic. In such cases the surface is extremely rough and well able to form a key for bituminous surfacing. A heavy bitumen such as Spramex will hold its position in all weathers without any particular movement or corrugation. Where a depth of 1 in or 1½ in. failure in the surface has

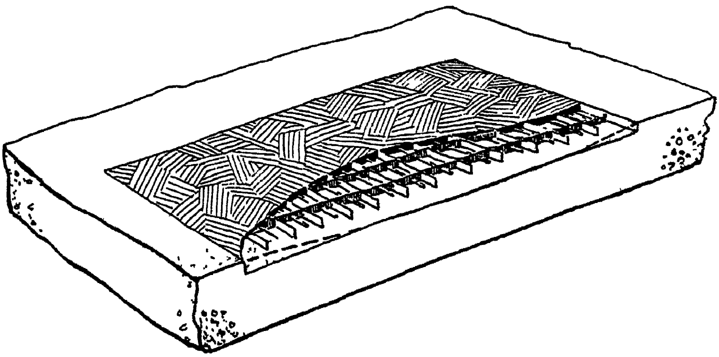


FIG. 140.—PATCHING SLIGHTLY WORN CONCRETE. SQUARE MESH WITH ASPHALTE.

occurred, square-mesh reinforcement filled in with hot asphalte will probably make an effective repair (Fig. 140).

This method has been used with conspicuous success in repairing sheet-asphalte roads where base cracks have caused failure in the surface; the reinforcement bridges the base crack, and the asphalte makes a complete joint at the surface

Repairs to failures or to trench disturbances in the body of a slab may be effected with safety by weak concrete filling for small areas, but for larger areas the method of treatment shown in Fig 120 may be applied.

The use of a linen or brattice-cloth between the base course and the wearing course has been used successfully to facilitate the repair of a worn concrete surface.

CHAPTER XXII

ROAD CORRUGATION

THE problem of corrugation, or waving, on road surfaces, is probably one of the most difficult and costly propositions confronting the road engineer at the present time It is, without doubt, a direct result of the development of the mechanically propelled vehicle, although it may have occurred in a mild degree in the days of horse traffic by the rolling action of wheels and, initially, of the road roller.

There are two leading factors in modern commercial traffic contributing to the destruction of roads by wave formation :—

1. Rear-axle or rear-wheel driving.
2. The solid rubber tyre—in various stages of wear.

It will be necessary to keep in view these two points in the following treatment of the subject.

The Occurrence of Corrugation.

Wave formation tends to occur upon almost every kind of road surface subjected to heavy motor traffic. There are one or two possible exceptions—viz. granite setts upon concrete foundation or concrete paving alone. In the case of the former, the rows of setts cannot easily become wavy, since there is only a thin sand cushion beneath and good jointing of the setts themselves. With concrete paving the success in resisting corrugation depends on the degree of smoothness and the rarity of cracks and joints in order to obtain an even tractive resistance to the passage of wheel traffic. Broadly, the tendency of a surface to corrugate varies directly as the tractive resistance. The lower the tractive resistance the less chance is there of waviness being set up.

The table on page 223 (column 2) gives the results of tests carried out in 1919 by the University of California. The wagon employed was horse-drawn at 2·4 miles per hour and carried a load of 6,000 lb.; the pull was registered by the compression of a calibrated spring to a dynamometer, and also, graphically, on a strip of paper by a recording pencil. Whilst the speed of the wagon was low, the comparison is most useful. Another series of tests for tractive resistance has been carried out by measuring the petrol consumption over different types of road surface; these are shown in column 3.

It must be borne in mind that the tractive resistance on the same road varies with the climatic conditions and the kind of tyre fitted

to the wheels. One surface having a high traction in wet or hot weather may have a much lower value in cold, dry weather. This fact indicates that under certain conditions the chances of wave formation are very small, even upon a second-class road. Whilst the actual waviness on different road surfaces is more or less the same to the road user, the manner in which it is set up does vary considerably. Before proceeding with this part of the subject it is

VALUES OF TOTAL TRACTIVE RESISTANCE

	Lb. per 6,000 lb.	Ton-miles per U.K. gallon of petrol.
Concrete	83	38
Monolithic brick	—	37
Concrete with $\frac{3}{8}$-in. oil top	143	—
Asphalte	207	29
Waterbound macadam	225	—
Gravel (good condition)	225	26·5
Gravel (loose)	813	—
Oil macadam	258	—
Earth road	306	17·5

necessary to analyse the particular effect of back-axle driving and the features of the motor vehicle of to-day.

The driving force of the rear wheels at the road surface is tangential and horizontal only when the surface has an even and constant resistance to the movement of traffic, and in such circumstances no vibration would be set up. In practice this rarely occurs; it may happen, for instance, at low speeds on a good average road or on a road having concrete for foundation or surface. We may assume, however, that on the roads where corrugation is set up this does not occur, and that in the early development of waves there is some weakness or obstruction causing it.

Most observers will have noticed that waves sometimes form in small groups in the vicinity of some weak spot or rigid iron cover in the road surface, and that certain portions of the road on straight lengths are practically free from waviness.

In the first instance, a study of the effect on the vehicle and the road of the front wheel striking an obstruction, as shown in Fig. 141, will explain the vibration and corrugating effect set up in the vehicle.

The driving force at wheel B is transmitted partially through the chassis in F to overcome the front-wheel resistance. A sudden increase in the latter—say, f—causes the force F also to increase, and the moment of the couple becomes $(F + f) \times y$. A vibration is therefore set up of the rear axle about the front axle, the moment

of which is fy. This vibration, harmonic in character, causes periodic wear at the driving-wheels, and thus produces waves.

It is, however, in the variable resistance to the rear or driving-wheels that the principal cause of corrugation will be found. It will be assumed that the driving-wheel strikes an inequality, either

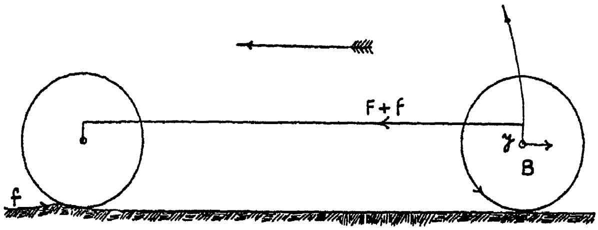


FIG. 141.—EFFECT OF FRONT WHEEL OF VEHICLE STRIKING AN OBSTRUCTION.

in the form of a slight hollow or raised obstruction. Immediately, the tangential force at the point of contact changes from the horizontal, as shown in Fig. 142, so that the force at the hub of the wheel which drives the vehicle is now partly horizontal and partly vertical. This can be resolved into horizontal and vertical components. The vertical component, depending as it does on the height or slope of the hump or hollow in the road, is the force to which must be added

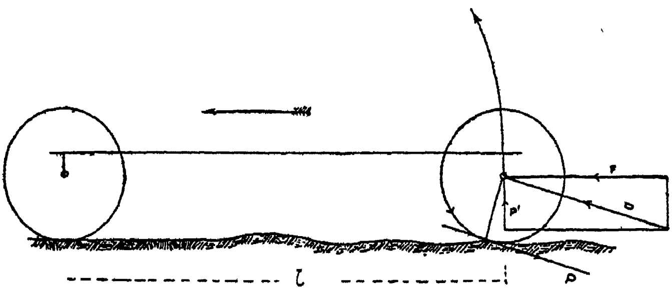


FIG. 142.—EFFECT OF REAR WHEEL OF VEHICLE STRIKING AN OBSTRUCTION.

the reaction due to spring compression, to obtain the total effect on the rear axle. The result is that there is a strong upward force acting on the rear spring and, in a lesser degree, on the body of the vehicle, so that the rear wheel may leave the ground—or nearly so—and permit of racing of one or both wheels until they again strike the road by the gravity of the vehicle and the reaction of the spring. The road surface has now to resist two forces—viz. an approximately vertical force due to weight, and a tangential one due to driving action. The latter force has the effect of moving the fine

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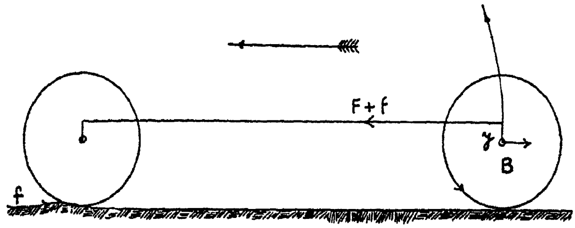

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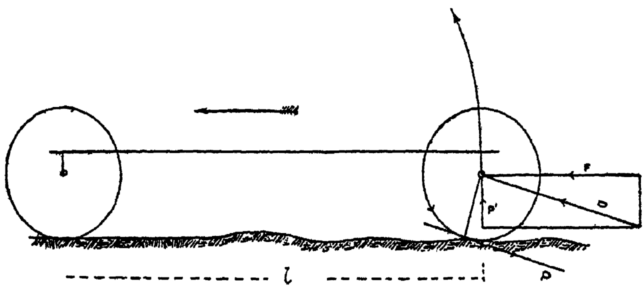

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the road surface towards the ridge which has just been
.
e of the waves so formed depends on the position in the vhether at the sides or in the centre portion of the road. s in the centre are more regular in shape, and often less than the waves at the sides of the road, where the wheels e direction only. The shape of the latter is different, wheels strike one side of the slope only, in consequence ıe other side becomes banked up by the ground-out

e of these waves, in a case taken near the channel and on milar to those shown in Fig. 143. The difference in the es on each side of the wave is most marked.

iliar wave-forming feature of the rear-wheel drive ed in practice by driving a motor-car over an obstruction the vibration, and then repeating the operation at the but running free. The vibration experienced, and its the latter case, is very much less than when the vehicle ring action.

point of interest is the influence of the wheel-base on iven vehicles. It has long been observed that vehicles g wheel-base were much steadier than vehicles possessing el-base. The explanation of this is to be found in Fig. he vertical component rotates about the front axle, the ing the wheel-base, l. It would appear that the question , as in the case of a cantilever having a load at one end, the case, and that the effect of the periodic upward at the rear axle on the mass of the body itself varies the cube of the wheel-base (l^3). It is certain that there ference in behaviour on a bad road between a vehicle vheel-base and one with a short wheel-base.

ly, where there are several vehicles of the same type and gth of wheel-base running upon a particular road, the effect is infinitely greater, because each one of them ie same manner, and waviness is quickly set up. There good ground for suggesting that motor-buses on a par-e should be varied in design, especially in the length of Standardization of this kind in motor and other similar ot to be desired, from the road engineer's point of view.

king.

n is caused by the continual braking of vehicles in the of a road. The reverse action to driving and the ne or both rear wheels to skid put a great strain on the

wearing surface and waves occur, as shown in Fig. 143. Waviness of this kind is often noticed at busy bus-stopping places.

Corrugation on Hills.

Corrugation on hills has often been observed when it has been more or less absent on the flatter sections of the same road. There are several reasons to account for this trouble on gradients. The speeds on the up-grade are high at the bottom of the hill, and the driving strain at the road surface is greater than normal; braking action for down-traffic is often a serious factor in wear of the surface. The natural effect of these forces is that the road surface is deformed or worn comparatively quickly by the excessive strains and vibrations imposed upon it by a variety of traffic. The tendency for movement is, of course, in a downward direction in every case, and waviness is quickly set up. As previously mentioned, however, it is more likely to occur at the foot or the top of the hill, or indeed at any change of direction. The movements of granite setts on ballast

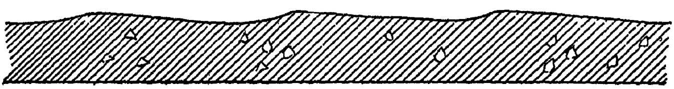

FIG. 143.—SHAPE OF WAVES ON HILL SURFACES, SIDES OF ROADS, AND AT CROSSINGS, DUE TO CONCENTRATED BRAKING EFFECT.

foundation on the down-side of a heavily trafficked road cause a segmental shape of the courses by the pushing effect of the traffic, with consequent tilting of the setts, and corrugation.

Wear at Bends.

It has been previously pointed out that without superelevation at curves an excessive wear or deformation of the road surface is bound to occur. When a motor vehicle is rounding a bend the pressure on the outer wheels is increased and that on the inner wheels decreased. So far as the front wheels are concerned this is not very material, but in the case of the rear wheels the question of driving adhesion arises. The reduction of pressure on the inner wheel at certain speeds will permit of slipping, so that by aid of the differential gear this wheel races. A transverse vibration, due partly to the turning movement and partly to some unevenness in the road surface, is set up, and the inner wheel misses and slips the road alternately, thereby causing considerable damage and wave-formation.

On the other hand, the increase of pressure on the outer wheel, together with the alternating drive due to the racing of the inner wheel, also assists materially in the production of waves. Observations of motor vehicles passing round a curve will confirm these views.

The inner driving-wheel bounces readily, and the smoothness of the road is quickly destroyed.

The trouble of waviness at bends will be partially or wholly remedied by adequate superelevation, and/or by the use of concrete foundations or surfaces.

Causes of Skidding.

Whilst discussing the corrugation of road surfaces at bends, one of the chief causes of skidding reveals itself. If one wheel is driving hard while the other is racing and the vehicle turning, the thrust is one-sided and not central, and the rear portion has a definite tendency to move sideways by skidding. For similar reasons a sudden application of the brakes will cause the vehicle to behave in the same way. It is sheer folly to apply brakes when the vehicle is changing direction; the front wheel should always be steered straight when braking is done.

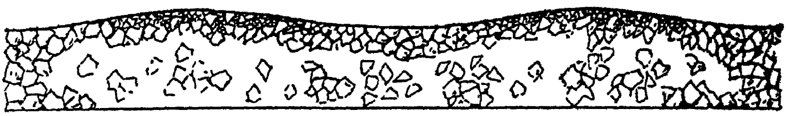

FIG. 144.—TYPICAL SECTION OF WAVY WATERBOUND MACADAM ROAD.

Skidding on wavy surfaces is always probable, and will invariably occur if the road is well cambered or when making a quick turning movement to round other traffic.

If every driver understood the fundamental reasons underlying the skidding of rear-axle-driven motor vehicles there would be fewer accidents recorded on the public highway.

Water-bound Macadam.

The tar spraying of a water-bound macadam road will assist in preventing for a time the wave-forming tendency of traffic Fig. 144, as it keeps out the wet and partially resists surface movement. There is little doubt that, under certain favourable atmospheric conditions, ordinary well-constructed tar-sprayed macadam forms a strong road material which will offer considerable resistance to the corrugating tendency of traffic. The tar-sprayed topping frequently corrugates with the tarred chippings forming the ridges.

Corrugation of Bituminous Macadam Roads.

The formation of waves on tar macadam roads is brought about by the fine tarred topping course moving backwards and forwards

into waves whilst the base course of larger material is worn bare in the hollows. This can readily be tested by driving iron pins into the road in definite positions and at intervals, longitudinally, of 18 in. to 2 ft. By this means some of the pins will occur approximately in the hollows, while the others will occur in the waves themselves. in the former case the pin-heads will be exposed and in the other they will be buried by the fine tarred topping—in the case of tar-sprayed roads, the tar and chippings—which have formed the ridges. The

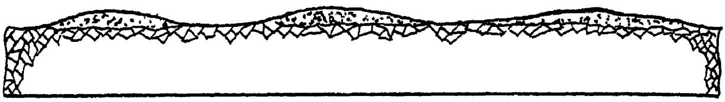

FIG. 145.—SECTION OF CORRUGATED TAR MACADAM ROAD

fact is that the rear-axle-driven vehicle pushes the tarred topping backwards and forwards into waves at the same time that it grinds down the lower course.

The manner in which tar macadam roads become corrugated is shown in Fig. 145.

In the case of tar-sprayed roads it is of the utmost importance that the chippings or sand should be applied evenly and the finished coat kept as thin as possible, in order to produce only shallow waves. Where periodic applications of tar and chippings are resorted to, corrugation may become a serious matter. An accumulation of fine

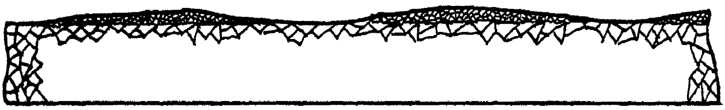

FIG. 146.—CORRUGATION OF REPEATEDLY TARSPRAYED AND CHIPPED MACADAM ROAD.

material results, as shown in Fig. 146, and which, shaped into waves, interferes to an alarming extent with the safe passage of traffic.

If traffic is concentrated in streams or lanes, by reason of limited width and a large number of vehicles, waviness may be set up in both longitudinal and transverse directions. Especially is this the case with an excess of fine material and in warm weather conditions, when the concentration of wheels squeezes the topping to the sides as well as grinding it into waves. Another factor influencing this deformation is the creeping of the surface material from the crown to the channel, thus causing a greater thickness at the sides than at the crown. Naturally, therefore, the waves in the middle portion of the road are likely to be less serious than those nearer the channel; longitudinal grooves are also less prominent at the crown for the same reasons.

The remedy for waviness on roads of this character suggests itself at once to the engineer who is thoroughly conversant with the cause of the trouble; i.e to remove the corrugated fine material. Generally it will be found that the large aggregate is standing quite well and that the waves can be obliterated by scarifying and the removal of loose material, and then re-surfacing with topping by tar-spraying.

Influence of Road Roller.

There is a considerable body of opinion which holds that corrugation is due to initial waving with the road roller, and there is no doubt that in a great many instances initial waves are present when the rolling is finished. The Author has noticed bituminous macadam roads badly waved by incompetent rolling. It is necessary that the greatest care and skill should be employed in carrying out rolling operations. The roller should not be a very heavy one, especially in the early stages of consolidation, although heavy rolling is recommended for clinker asphalte. Light and heavy rolling and also diagonal rolling are all useful in preventing wave formation

The Crompton three-axle roller, designed by the late Colonel R. E. B Crompton, C.B., was arranged to eliminate waves by means of a specially mounted centre axle which crushed down any humps formed by the other rollers. The machine is an interesting example of the attention given to this important phase of road work by an eminent engineer.

Whilst this roller cannot be praised too highly, it is generally recognized that a two-axle roller in the hands of a skilled operator will produce a reasonably smooth surface.

Reinforcement of Asphalte to Prevent Corrugation.

As previously mentioned, corrugation readily occurs on asphalte surfaces at bus stops or on busy crossings where braking of the same type of vehicle occurs very frequently. This can be prevented by relaying the asphalte with a square-mesh reinforcement, having squares of 4–6 in., 1¼-in.-depth metal. The narrow edge of the metal is level with the asphalte road-surface and takes the wear. This method has been employed at important bus stops with considerable success. The metal becomes polished by the action of the braked wheels, and no corrugation is set up.

Corrugation on Concrete Roads.

This type of road would appear to satisfy one of the first requirements for the prevention of wave trouble, in so far as it presents a smooth, rigid surface, and therefore offers a low tractive resistance

to traffic with an absence of vibration. It seems probable that transverse joints, unless formed obliquely, may prove to be a source of weakness, and perhaps the starting-point for setting up waviness. Much will depend on the care with which the concrete is laid.

Earth Roads.

In hot, dry climates, where earth roads predominate, the surface becomes corrugated almost immediately after blading. It is a curious fact that a well-sprung car can travel over the wavy surface better at high speeds than at low speeds; at 60 m.p.h. the wheels seem to contact the tops of the waves only.

CHAPTER XXIII

MEASUREMENT OF WEAR

THE measurement of wear of road surfaces is useful in order to estimate from time to time the suitability of the paving and the probable life of the road. In the case of roads built upon a non-rigid foundation the difficulty is to estimate what proportion of the wear recorded by the instrument is due to a settlement of the road, and not to legitimate wear from traffic; this point has also to be considered in connection with bituminous roads, even when laid upon reinforced concrete, as this material permits a certain amount of compression in itself without a relative loss due to wear.

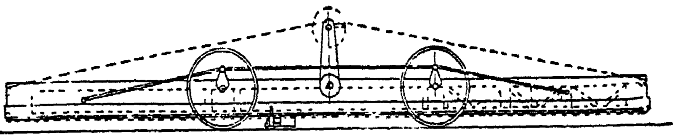

FIG. 147.—ROAD BOARD "PEN CARRIAGE" FOR MEASURING WEAR.

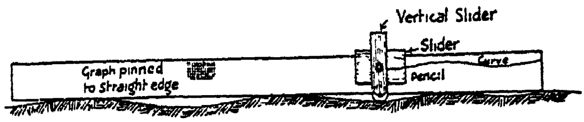

FIG. 148.—SIMPLE FORM OF STRAIGHT-EDGE FOR MEASURING WEAR.

Measurement of wear may be carried out by taking cross-sections at certain definite points along the road with reference to heights or bench marks at the side of the road. Wire is strained across, at a given tension, from standards fixed in cast-iron sockets on either side of the road. This method does not go far enough, since it does not show the waviness of the surface. In point of fact, it is not improbable that the cross-section may show an elevation or raising of the surface, owing to its occurrence at the crest of a wave; on the other hand, it may show a depression, if it happens to occur at the hollow of a wave. It is necessary, therefore, in order to examine fully the wear of the road, to take longitudinal sections as well as cross-sections.

The tracing of the longitudinal section may be carried out by using a portable 18-ft. straight-edge, as adopted by the Road Board some years ago (Fig. 147), or a simpler form of this instrument as shown in Fig. 148. It consists of a wooden straight-edge 12 ft. long by 4 in. by 1 in. strengthened by a light angle-iron to prevent

twisting, and a chart fixed to the side of it. A special horizontal slider containing a vertical slider and pencil runs on a wheel along the bottom of the straight-edge, and the slope of the wave is recorded exactly on the graph. For subsequent records at the same point the straight-edge should be set to the same position by reference to the fixed bench-marks, so that the road surface is again traced on the same graph, thus showing the movement of the wave or the development of the wave-crests.

With regard to cross-sections, these will indicate the variation in wear between crown and channel. A complete record of this variation will be obtained if two or three cross-sections are taken close together, say at 1 ft. intervals, so that at least one crest and one hollow will occur approximately on these sections. Moreover, the instrument may be used longitudinally over the particular section of road to complete the examination of wear.

A similar apparatus to the Road Board Carriage has been used in Germany; it is known as the Kohler profilometer.

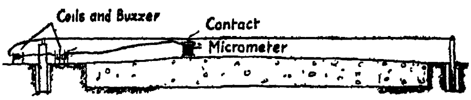

FIG. 149.—U.S.A. APPARATUS FOR MEASURING WEAR OF CONCRETE ROADS.

Measurement of Wear on Concrete Roads.

Measurement of the wear of the concrete road is perhaps of more importance than that of any other type of road, as the reduction in thickness represents a more serious reduction in strength, having regard to the fact that the strength varies approximately as the square of the thickness.

The apparatus used by the Bureau of Public Roads consists essentially of a fine wire stretched tightly across the road at a constant height, together with an inside micrometer for measuring the distance from the road surface to the wire, as shown in Fig. 149. The wire is stretched at a tension between two blocks at either side of the road, which are provided with adjustable screws and a rod resting on the flat tops of a bronze plug at a depth of $\frac{3}{4}$ in. below the level of the surface. An electric buzzer is mounted on the side of the blocks, and a micrometer which measures the depth below the wire at 1 ft. intervals is provided with a flexible wire so that the circuit is completed as soon as contact is made. The instrument registers to the nearest 0·001 in. if required.

Another machine, portable, for testing the hardness or wearing qualities of concrete, has been designed by the U.S. Bureau of

Public Roads; it consists of three narrow steel wheels 8 in. diameter by $\frac{1}{4}$ in., rolling within a frame at constant speed of 35 r.p.m., around a circle of 21 in diameter; it is driven by a $1\frac{1}{2}$-h p. motor

Frequent readings are taken by micrometer dial and revolution counter.

When the pavement is moist, the wear is small because damp particles protect the path.

Arlington Wear Tests show that gravel with rounded particles is as satisfactory for concrete paving as angular or crushed fragments.

Tests to Determine the Wearing Qualities of Aggregate: French Coefficient of Wear.

The determination of the wearing qualities of aggregate is performed by means of the Deval abrasion machine. This consists of one or two iron cylinders mounted on a horizontal shaft so that the

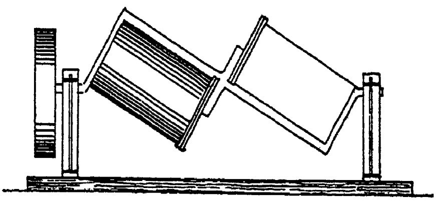

FIG. 150.—DEVAL ABRASION MACHINE.

axes of the cylinders make an angle of 30° with the shaft, as shown in Fig. 150. The aggregate is thrown from one end to the other, which action tends, by abrasion and impact, to break it into fine particles. The machine revolves at a rate of 30 to 33 r.p m. for 10,000 turns, and the worn material which will pass a $\frac{1}{16}$-in. mesh is considered the amount of wear.

Then the French coefficient of wear $= \frac{400}{W}$, where $W =$ weight in grams of the detritus under $\frac{1}{16}$ in. size per kilogram of rock used

A good wearing rock should give a coefficient of about 20, which value has been adopted as a standard by French engineers. Above 20, therefore, the wearing quality is very high, and below 10 it is low.

Attrition Test.

This test is made in the four-cylinder Deval-type machine; 11 lb. (5 kg.) of rock, numbering as nearly fifty pieces as possible, are placed in a cylinder, and the machine revolved 10,000 times at a rate of about 30 per minute. In the wet test 1·1 gal. (5 litres) of water is

placed in the cylinder with the 11 lb. of stone The percentage of loss is estimated from the amount of material removed which will pass through a sieve of $\frac{1}{16}$ in. mesh.

Resistance to Abrasion.

The tests are made in an abrasion (or hardness) machine of the Dorry type. The specimen is prepared in the form of a cylinder 1 in. diameter, 1 in long. This is held in contact with the rim of a rotating cast-steel disc under a pressure of 3·5 lb. per sq in. (250 grams per sq. cm). Crushed quartzite, to act as abrasive, is fed continuously upon the surface of the disc. The loss of weight of the specimen is determined after 1,000 revolutions of the disc at about 28 r.p.m

Repeated Blow Impact Tests.

These tests are made in a Page impact machine. The specimen is prepared in the form of a cylinder, 1 in. diameter, 1 in long. The hammer of the testing machine weighs 4·4 lb. (2 kg). The test consists of a 0·4-in. (1 cm.) fall of the hammer for the first blow and an increased fall of 0·4 in. (1 cm.) for each succeeding blow until failure of the specimen occurs. The number of blows required to cause failure is taken to represent the toughness of the rock.

Cementation Value of Rock.

For the purposes of the tests, the rock is ground up with water in the standard Ball mill, and from the resulting paste six briquettes are formed under a pressure of 1,880 lb. per sq. in. (132 kg. per sq. cm.). These briquettes are dried for twenty-four hours and then tested under repeated impact in a Page impact machine, and the number of blows necessary to destroy the resilience of the briquette is determined. This number is taken to be the cementing value of the material.

Tests for Absorption.

These tests are made by drying the sample until it is of constant weight, and then immersing it in water and weighing immediately after immersion, and also after immersion for four days.

New Ways of Testing Aggregate.

Experiments by the use of microphotography and the Röntgen-ray consist in enlarging by special apparatus, with the aid of the microscope, samples of concrete which are observed by means of transmitted or reflected light. In the latter case the surface of the

object is illuminated by a 1,250-c.p. Osram-azo-projection lamp, carried on a double swivel and mounted so as to be directed to any required angle. The microphotographs indicate clearly the presence of pores or bubbles in defective concrete and also the process of rust formation.

The Röntgen ray has been used upon samples of reinforced concrete to detect the presence of rust and the influence of rust-forming ingredients. It is necessary that the condition of the iron at the time of placing in the concrete should be known, in order to follow the changes taking place in the mass by observations at regular

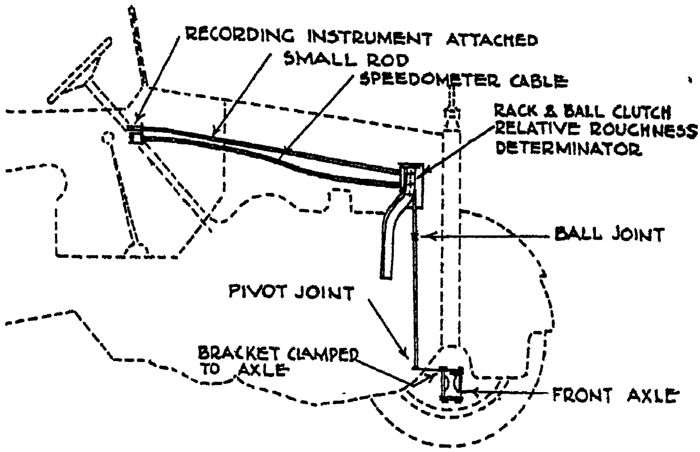

FIG 151.—DIAGRAM OF ROUGHOMETER.

intervals. These experiments indicate that the permeability of the concrete to the rays decreases with the increase of the proportion of the cement used.

Measurement of Unevenness by the Vialog or Roughometer.

The profile of a road surface may be recorded by an instrument known as a "Roughometer". This is a recognized instrument which, when attached to a motor vehicle, records the variations in the profile of the road in a longitudinal direction.

The apparatus is clamped to the front axle, the vertical movement or compression of which is transmitted through a vertical rod with pivot-and-ball joints as shown in Fig. 151. The accumulation of this vertical movement is transmitted through a rack-and-ball clutch which thus determines the relative roughness, this in turn is recorded by a speedometer coupled to an instrument on the dash-board. The device is arranged so that 1 in. of movement of the rack registers one unit on the dash-board instrument.

This instrument should be utilized by all road authorities in order to keep a reasonably accurate record of the state of each road.

The impact or vibration factor per mile is as follows :—

Less than 50 . .	no vibration.
100–150 . . .	noticeable impact and vibration.
150–200 . . .	vibration and lurching.
300 or over . .	serious impact and dangerous surface for light cars.

Tyre-chain Wear Tests.

An investigation of wear due to winter tyre chains has been carried out by A. T. Goldbeck by tests on sample asphaltes with the road machine, to compare with the paving on a road carrying 10,000 vehicles each way per day; the tests were made on the samples in wet condition at 75° F. and 34° F. with a pneumatic tyre fitted with a tyre chain. Sand-carpet and fine-graded bituminous concrete of the hot mix type showed high durability; limestone " amiesite " $\frac{3}{8}$-in. gauge is superior to $\frac{5}{8}$-in. gauge under this test.

CHAPTER XXIV

SLIPPERINESS AND ITS TREATMENT

THE problem of "skidding" on wet road surfaces has exercised the minds of all those interested in the construction of roads and the design of vehicles. The increasing number of motor vehicles travelling upon our highways, coupled with the continual wet weather experienced during recent years, makes the question one of great urgency.

It is perhaps expedient to examine briefly the principal causes of skidding before discussing remedies.

The onus would appear to lie with the road engineer rather than with the vehicle designer, as the condition of the road surface in wet weather is primarily responsible for a skid.

The following may be said to be the principal causes of the trouble :—

1. Smooth, fine road surfaces of bituminous asphalte, having a low coefficient of friction when wet; caused too, by wear and by hot weather.
2. Excessive camber or crown.
3. Camber construction of roads at bends also on slow curves.
4. Corrugation or waviness of the surface.
5. Light rainfall which moistens the foreign matter (such as oil) on the surface, without scouring it.
6. Insufficient weight on the rear axle of the vehicle, or lack of balance in loading.
7. Back-axle driving and braking, under the action of the differential gear.
8. A sudden change in the nature of the road surface.
9. Worn tyres, or unequal inflation.
10. Driving in "top-gear" on obviously slippery and dangerous road surfaces.

Remedies.

Generally, with bituminous surfaces it is a good plan (*a*) to have suitable bituminous compositions which have the maximum permissible proportion of large aggregate; (*b*) to roll plain or pre-coated chippings into newly laid surfaces or (*c*) to flush and/or to grit greasy surfaces.

With regard to concrete paving the finish of the surface is most important in this connection.

Tests carried out by the Road Research Laboratory at Glamorgan showed that with dry concrete and the use of a heavy screed the side way force coefficient of the new surface was reduced—i.e. using the skidding motor cycle for recordings—with a wetter mix, however, the skidding resistance was greater when the heavy screed was used.

Skid Tests in Virginia (U.S.A.).

Some interesting tests on skid resistance have been carried out by Messrs. Shelburne and Sheppe in Virginia, on some thirty-two pavement surfaces in wet and in dry condition. The test car, moving at 10, 20, 30, and 40 m.p.h., respectively, was brought to a stop by braking on all four wheels; at the instant of braking, a detonator, attached to the running board, fired a chalk bullet on the pavement; the stopping distance was measured back to the chalk mark.

The tests were carried out on various types of bitumen, asphalte, and concrete pavements.

At 40 m p.h. measurements ranged from 63·6 to 88·9 ft. on dry and from 72·0 to 254·5 ft. on wet surfaces; some twenty-seven of these which had a harsh gritty surface had relatively short stoppng distances and high coefficients of friction; broom-finished concrete proved superior to smooth or belt-finished surfaces.

Non-skid treatment reduced the stopping distance in some cases from 224 to 94·7 ft.; worn tyres produced a skid 40% longer than good treads, and of these synthetic smooth tyres skidded 12% longer than comparable natural rubber tyres.

The average coefficient of friction, f, was computed from the formula

$$f = \frac{v^2}{30}S$$

where v m.p.h. = initial speed at time of braking and
S = the average stopping distance in feet.

Four different types of tyre treads were used—viz., (*a*) new, with 23% natural rubber; (*b*) almost new, natural rubber; (*c*) smooth, synthetic rubber; and (*d*) worn natural rubber.

The diagram (Fig. 152) shows the resistance to skid on two wet surfaces of broom-finished concrete and sand asphalte; Fig. 153 shows the effect of non-skid treatment on wet surfaces at the several speeds.

Skidding Tests in India.

Some interesting tests were carried out by the Indian P.W.D.; two lorries at 15 m.p.h. came to rest (after braking on rear wheels

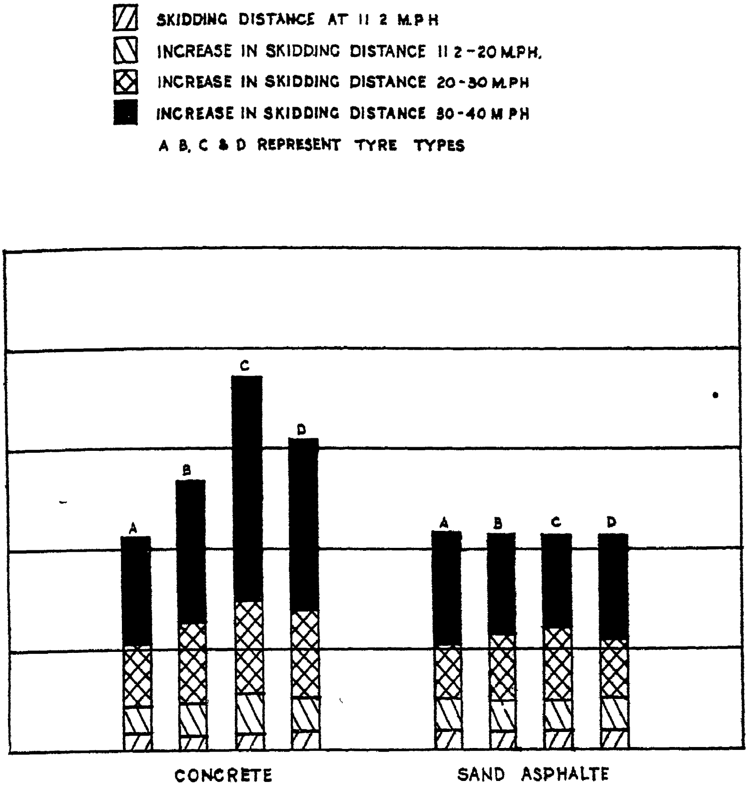

FIG. 152.—SKID RESISTANCE. MEASUREMENTS FROM TESTS IN VIRGINIA, U.S.A.

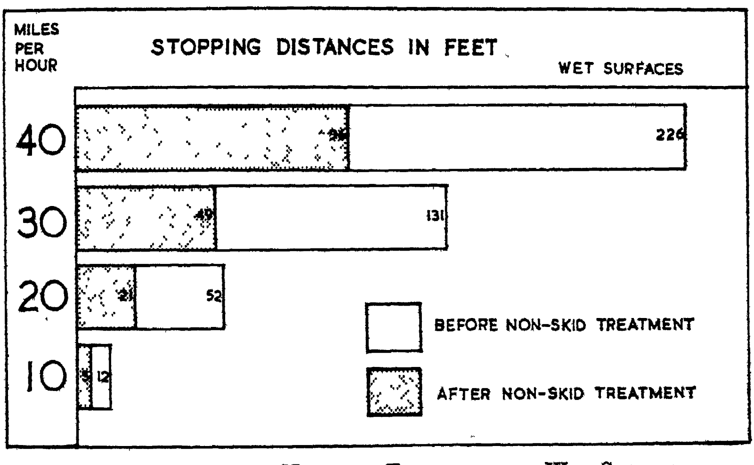

FIG. 153.—EFFECT OF NON-SKID TREATMENT ON WET SURFACES.

only) in 25 yd. and 15 yd., respectively, on a dry road, but both in 50 yd. on a greasy road.

In the former, the kinetic energy at the start

$$= \frac{Wv^2}{2g} = \frac{W \times 22^2}{2 \times 32{\cdot}2} = 7{\cdot}5W.$$

Thus $7{\cdot}5W$ was destroyed in 75 ft., therefore the retarding force

$$= \frac{\text{Momentum}}{\text{Distance}} = \frac{7{\cdot}5W}{75} = \frac{W}{10}.$$

As, however, two-thirds of the weight was carried on the rear axle, the coefficient of friction

$$u = \frac{1}{10} \times \frac{3}{2} = 0{\cdot}15$$

for the dry road for the first vehicle and 0·25 for the second.

On the greasy road, however, the value of u fell to 0·08 with each vehicle.

CHAPTER XXV

THE INFLUENCE OF TYRES, SPEED, AND VEHICLE-DESIGN UPON ROAD SURFACES

BETWEEN the two wars the scale of improvements in road construction and design was closely followed by improvements on a similar scale in tyre equipment and vehicle-design.

The highly destructive (from a road point of view) iron tyre gave way to the solid rubber tyre, and later to the cushion tyre, and to-day these are almost entirely superseded by the pneumatic tyre.

Various devices for sprung wheels have been placed on the market from time to time, but none of these can equal the efficiency of the pneumatic tyre, the general adoption of which must have made a tremendous reduction in the cost of road maintenance.

Impact.

As a matter of history in this connection, it is proposed to give a summary of the impact tests (given in detail in the first edition of this work) carried out about 1922 by the U.S. Bureau of Public Roads.

Two methods of measuring impact were devised as follows :—

(*a*) *By deformation of copper cylinders*, ½ in. diameter and in length, placed in the bottom of a heavy cylinder under a neatly fitting plunger which receives the impact from the wheel. The deformation is measured with a micrometer and compared with the deformation produced by static forces. Unfortunately, the cylinder acts to some extent as a cushion, and only the average force of impact is measured; the maximum impact, therefore, is approximately twice the average.

(b) *By the autographic method.* This consisted of a paper tape moved at right angles to the pencil movement at a known uniform speed. The pencil is operated by the vertical movement of the mass of the vehicle as it travels; thus a space–time curve is produced, and the second derivative of this curve will give the acceleration at any given point.

A special runway of concrete was constructed for the purpose of making the tests; it was designed so that the head of the plunger was flush with the road surface. The obstruction tests were made at this place by bolting to the plunger-head a strip of hardwood 4 in. wide and 16 in. long, using thicknesses of ¼ in., ½ in., 1 in., 2 in., 3 in., and in the case of pneumatic tyres, 4 in.

The "drop" tests were made at the drop-off edge *E* (Fig 154), the plunger beyond and in the lower pit being so placed that the plunger-head *A* may be elevated to give "drop" distances varying from 0 to 3 in. The plunger could also be moved away from the edge *E* any distance to receive the blow of the wheel as it jumped various distances depending upon the speed of the truck. The ½-in. copper cylinder, previously mentioned, was placed under each plunger in order to secure data from both types of tests during one passage of the truck.

The impact of only the left rear wheel was measured. A bridge was placed over each plunger-head to protect it from the front

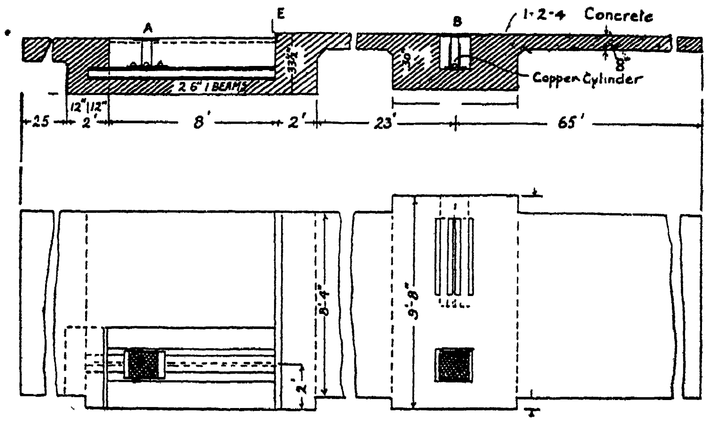

FIG. 154.—SECTION SHOWING SPECIAL CONCRETE ROAD CONSTRUCTION WITH APPARATUS FOR IMPACT TESTS. (U.S.A.)

wheel. As this wheel passed, the bridge was jerked out, leaving the plunger-head clear to receive the impact of the rear wheel.

The speed of the truck is regarded as one of the most important factors and one which is subject to more traffic rules than any other. The speed values, therefore, in miles per hour, have been made the independent variable in most of the tests.

Trucks or lorries of different weights and capacities have been used in these tests. The experimental results obtained have been plotted on no fewer than 133 charts. In several cases during the test it was noted that certain oscillations set up by the front wheel striking the obstruction were sufficient to change materially the impact of the rear wheel. The tests show the deformation of various kinds and conditions of tyres employed relative to load, and indicate clearly the high elastic value of the cushion and the low value of worn solid tyres: fortunately solid tyres have gone out of fashion.

In the obstruction tests a considerable change is shown in the impact value, but only a slight change in tyre deflection. Naturally

the impact value is greater for solid rubber tyres and less for the pneumatic tyre: at a speed of $17\frac{1}{2}$ m p.h. the pneumatic tyre gives an impact value of only 1·75 times the rear-wheel pressure on the road surface, the cushion tyre over three times, and the solids 4·3 to 5 1 times. The cushion tyre gives an impact value of 63% of the solid tyre average and the pneumatic only 36%. It will be observed that the impact value for the pneumatic tyre increases only very slightly with the increase of speed.

Another comparison of interest is that showing the relative values

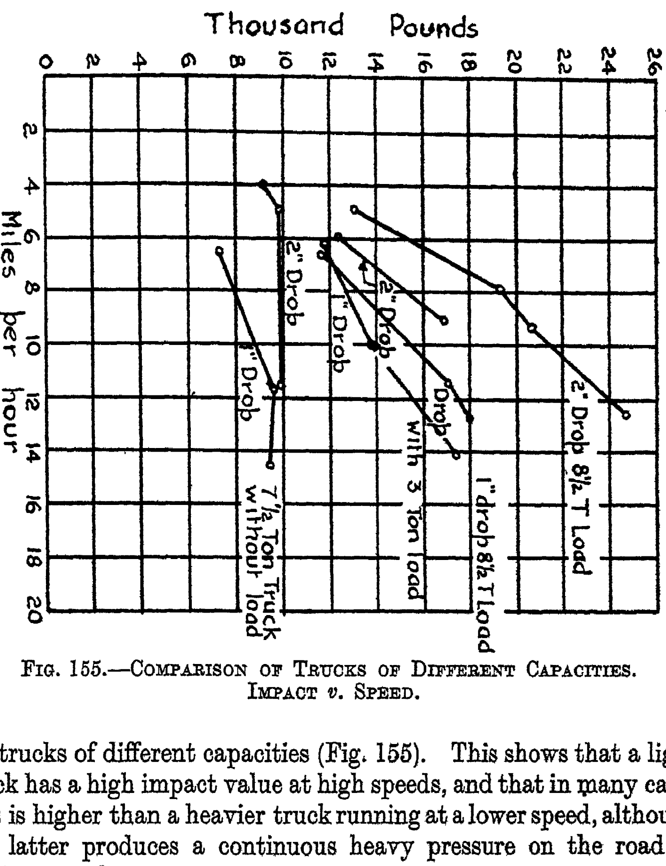

FIG. 155.—COMPARISON OF TRUCKS OF DIFFERENT CAPACITIES. IMPACT *v.* SPEED.

for trucks of different capacities (Fig. 155). This shows that a light truck has a high impact value at high speeds, and that in many cases this is higher than a heavier truck running at a lower speed, although the latter produces a continuous heavy pressure on the road in addition to the impact.

The dimensions and pressure of air in pneumatic tyres are matters of considerable importance. A large section of oversize of tyre will give better results than a small tyre, as it is equivalent to softening the leaf-springs of the vehicle, and the increased cushioning effect is most pronounced.

Another advantage claimed for oversize of pneumatic tyres is an increased mileage for a given quantity of fuel. There is undoubtedly

some truth in this contention, and it follows naturally that the wear on the road surface is reduced proportionately

With regard to the air pressure in the tyre itself, this is a matter of finding a mean value which will afford reasonable comfort and at the same time obtain the maximum wear from the tyre. A low air pressure gives the greatest cushioning effect and does a minimum amount of damage to the road surface, but it is not good for the life of the tyre, and moreover the vehicle is not safe on the road under such conditions. Many accidents have occurred through the bursting or skidding of soft tyres, and the safer method is to have the

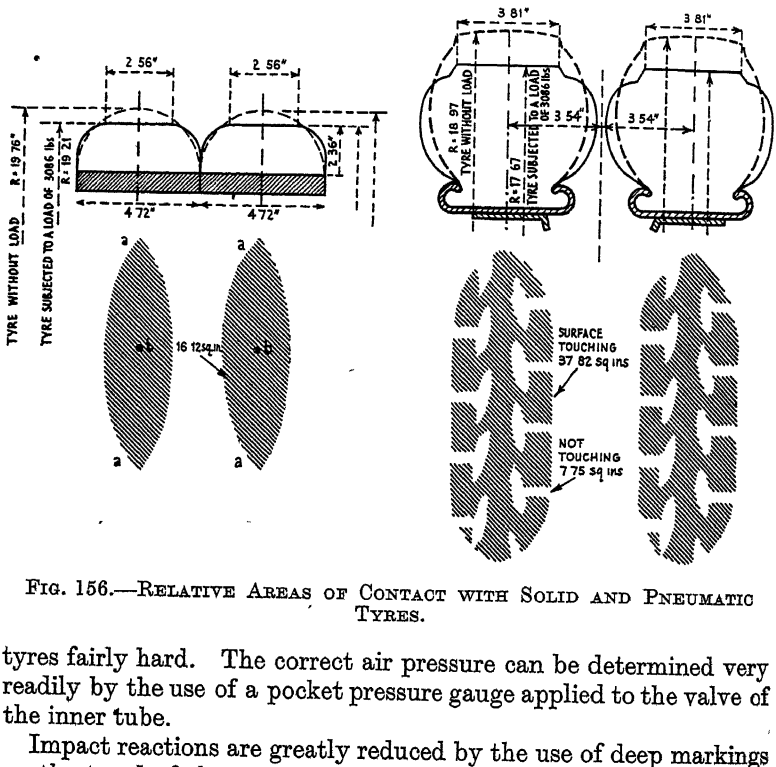

Fig. 156.—Relative Areas of Contact with Solid and Pneumatic Tyres.

tyres fairly hard. The correct air pressure can be determined very readily by the use of a pocket pressure gauge applied to the valve of the inner tube.

Impact reactions are greatly reduced by the use of deep markings on the tread of the tyre. Thickness and narrowness of tread are necessary to reduce impact reaction.

Comparison of Pressure Intensities of Pneumatic and Solid Tyres on Road Surfaces.

A further comparison of the effect of pneumatic and solid tyres on road surfaces is available by reference to the diagram shown in Fig. 156; which represents the tyres used in certain experiments

carried out in France In the case of the twin solid tyres, the area of contact with the road, when under load, is shown by the shaded area equal to 16·12 sq. in. for each tyre; this area is by no means under an equal intensity of pressure—assuming, of course, smooth rolling conditions—and at points marked (*a*) the pressure will be practically zero. The maximum intensity of pressure will occur at (*b*)—i.e in the centre of the area—and from this point it will decrease to a greater or lesser extent in different directions towards the edge.

The area of contact of one pneumatic tyre under similar loading W is 37·82 in., and the area covered, but not touching, owing to non-skid marks is 7·75 sq. in. In this case the intensity of pressure over the shaded area is practically uniform, since this is transmitted and distributed by the air pressure itself.

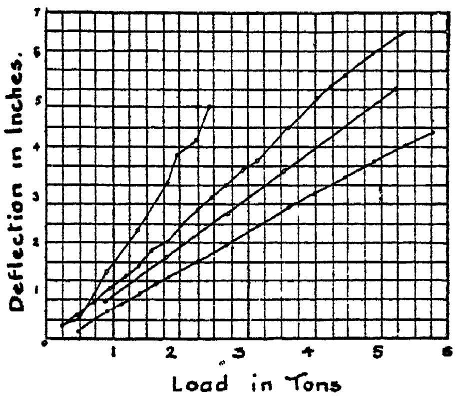

FIG 157.—COMPARISON OF SPRING DEFLECTION *v.* STATIC LOAD.

Assuming a maximum intensity of pressure, P, in the solid tyre equal to twice the average, the value becomes $P = \frac{2W}{16 \cdot 12}$ and for the pneumatic tyre $P = \frac{W}{37 \cdot 8}$; roughly a proportion of $4\frac{1}{2}$ to 1.

It is not difficult, therefore, to realize the great benefit to road surfaces obtained by the use of pneumatic in place of solid tyres.

The Springing of Vehicles.

This problem has received great consideration in recent years and the impact of the best sprung cars has been reduced to a minimum by well designed springing.

Fig. 157 shows a comparison of deflection, in inches against static load in tons, on four different springs, and indicates that generally the ratio may be shown by a straight-line curve.

Another factor of importance in connection with leaf-springs is that of lubrication · this is frequently neglected and virtually causes an increase of unsprung weight on the road; to obviate this all leaf-springs should be lubricated frequently.

Wheel-base and Rear Overhang.

It has been shown that a long wheel-base brings about steadier running on the road. Clearly, then, a variation of wheel-base of traffic passing over the same highway would have a beneficial effect as compared with vehicles having the same wheel-base. A long wheel-base vehicle, however, requires a greater width or space for turning, and difficulties when turning into narrower carriage-ways may arise owing to the rear wheels cutting in with a sharper curve. The amount of overhang at the rear of a motor vehicle naturally determines the relative proportions of the load coming upon the rear axle. It also may increase the vibration of the rear part of the load to a serious extent. The portion of the load behind the rear axle has a lifting tendency on the front axle, and it would appear, therefore, a better arrangement to have the centre of the load as far in front of the rear axle as is practicable. A long overhang is a great danger in case of rear skidding, and is to be deprecated. Many accidents happen in this way, the rear part of the vehicle swinging round and doing damage on the footpath, to pedestrians, or to lamp-posts and similar obstructions.

Differential Gear.

As shown elsewhere, it is extremely doubtful whether this feature of axle design is as good for the road as for the vehicle; indeed, it is not always a good thing for the vehicle, because one wheel only may be driving or braking and not the other—a condition of things likely to produce skidding.

Centre of Gravity.

A high centre of gravity of a loaded or unloaded vehicle should be avoided in all vehicle design.

For stability at curves or during a " turn ", symmetrical loading is desirable. For example, a lorry carrying a heavy girder diagonally might in consequence be in grave danger of skidding or of overturning.

The Four-Wheel Drive (F.W.D.).

The references made elsewhere to the destructive effect of rear-wheel driving (R.W.D.) naturally lead to the conclusion that some

other form of drive might be less objectionable. The four-wheel drive, or F.W.D., as it was called during the First World War, seems to offer many advantages over the rear-wheel drive. The effort at the driving-wheels is reduced at least 50%, and the mass of the vehicle is being jointly pulled by the front wheels and pushed by the rear wheels. This eliminates almost entirely the "rear-axle kicking," referred to in Fig 142, and the tendency of this type of vehicle to create waves is relatively small

Three-axle Truck.

A good example of distribution of the drive through two axles is afforded in the impact tests of the U.S.A. Bureau of Public Roads, with a special six-wheeled truck having two rear driving axles and pneumatic tyres, as shown in Fig 158. The weight was distributed

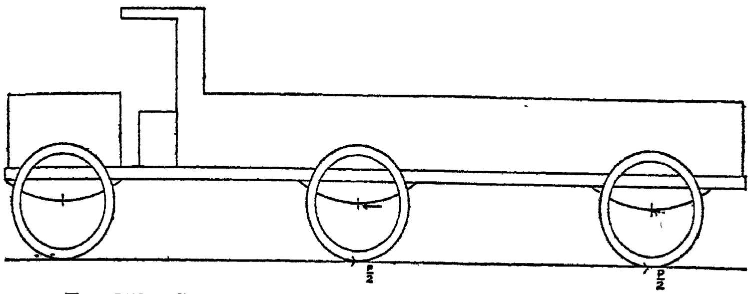

FIG. 158.—SIX-WHEEL VEHICLE WITH FOUR-WHEEL DRIVE AND PNEUMATIC TYRES.

over the four rear wheels instead of two as on the ordinary vehicle. The tests show that the impact is practically constant for speeds between 10 and 25 m.p.h., and that the combined impact for the two left rear wheels is less than the total load on those wheels.

The Renard train has proved the soundness of the theory of loads on two driving axles; in addition less damage is done to the road surface.

Loadometers.

These instruments are portable jacks intended for testing the axle weights of vehicles on the road by placing under the axle and raising it slightly from the ground. They form a very much simpler arrangement than the ordinary weighing machine. Many of the older weighing machines are too small to accommodate complete vehicles, either for width or length, and are quite inadequate to deal with modern traffic; some other system like the loadometer is necessary to deal with this problem.

Investigations on Tyre Wear.

Investigations in Iowa on tyre wear and costs have yielded some interesting data on this question; the results may be summarized as follows :—

(*a*) Variations in car speeds cause greater differences in the rate of tyre wear and tear than variations in braking and accelerating, type and condition of road surfaces, tyre-inflation pressure, or in any of the other factors indicated.

(*b*) Tyre wear on concrete pavements at 65 m p.h. is four times that at 25 m.p.h.

(*c*) Abrasive surfaces cause a great increase in tyre wear; asphalt with soft limestone chips reduces wear to a value pro-rata of the speed.

(*d*) Tyre wear at higher speeds is due to bouncing and slipping, increased traction at rear wheels and increased brake applications and braking time.

(*e*) In city traffic the wear at " stop " and " go " signals is seven times that in rural areas at a speed of 25 m.p.h.

(*f*) The wear on dry pavements is double that on wet pavements.

(*g*) Lack of wheel alignment causes rapid wear of tyres.

(*h*) Rear wheels wear at about twice the rate of the front wheels.

(*i*) On curves at speed, if tyres " scream " the wear is increased ten times.

(*j*) Continuous operation at 65 m.p.h. on concrete pavements causes the pressure to increase 4·6 lb. per sq. in. This pressure increases 1 lb. per sq. in. for each 20° F. rise in the atmospheric temperature.

(*k*) Inflation pressure of 30–32 p.s.i. is recommended for greatest service.

(*l*) Costs in tyres and tubes operated on concrete pavements averages 0·18 cents per car mile; for bituminous surfaces 0·19 cents, and or gravel 0·37 cents per car mile.

(*m*) A speed of 35 m.p.h. is recommended for tyre conservation, also starting and stopping slowly, reduced speed on sharp curves, and checking tyre inflation weekly.

CHAPTER XXVI

TRAFFIC SIGNS

THE increasing number of types of traffic and warning signs, and the need for them have necessitated full co-ordination of type, size, and colour for universal use throughout Britain.

With this in view the Ministry of Transport has issued "The Traffic Signs Regulation, 1950", giving full details of all signs which are permitted on the public roads of this country. The wide variety of signs now authorized are to be sited and fixed according to circumstances and requirements.

Briefly, the signs may be referred to under the following headings :—

Warning Signs.

These are used to give special caution by reason of the source of danger specified in the sign; they are similar, generally, to those in use already. They include: Cross roads; different types of T Junction; Roundabouts; "Children" and Schools; Level Crossings; Road Narrows; Narrow Bridge; Low Bridge; Swing Bridge; Ford; Unfenced Road; Gate across Road; and the most important sign of "Pedestrian Crossing Ahead" (2 ft. 6 in. × 1 ft. 5 in.).

Direction Signs.

These indicate place-names and classification numbers as hitherto; they are arranged on the name-plate to show also arrow directions and place-names where several roads intersect or for staggered junctions.

Other signs indicate dual carriage-ways; by-pass and ring roads; route identification; local direction signs; cyclists; one way streets; Halt; Slow, Major Road Ahead; and parking signs.

Several of the signs indicate prohibitions or restrictions of the character indicated by the sign on the user of highways by vehicular traffic.

Carriage-way Markings.

Lines may be placed at places (*a*) where traffic must stop either by a constable on point duty or at a light signal; or (*b*) to show the course to be taken by traffic at road junctions, corners and curves; or (*c*) to show the proximity and situation of street refuges. The

lines are to be yellow or white, 5 in wide for transverse lines and 4–5 in for others; studs or plates may be used in place of painted lines.

Flashing Beacons.

These show an intermittent red light as a warning at important cross-roads; they may be used also for temporary road works.

Light Signals.

These are now universally used for the control of vehicular traffic; the signals must provide three lights to face each stream of traffic to be controlled—one red, one amber and one green; the diameter of the lenses is from 8 to $8\frac{1}{4}$ in., and the normal height to the green lens is 7 ft. 6 in.; where road gradients occur it may be up to 10 ft. high.

The word "STOP" in black letters must be shown on the red lens

In many countries signal control is effected from one suspended at a height of 14 ft. or more at the centre of the intersection. Generally these signals work quite well and drivers become accustomed to them; one disadvantage is that, if set higher than 14 ft., visibility is difficult from the leading car.

The sequence of the lights is Red (Stop), Amber with Red (warning for Green), Green (proceed), Amber alone (Stop, unless too far ahead to stop safely).

In the United States it often occurs that the Amber sign is eliminated; this avoids any confusion or accident by two streams of traffic endeavouring to cross over on the Amber; the method works quite satisfactorily.

The illumination of each lens should be carried out by independent lamps of not less than 100 c.p. The casing of the lenses should be so designed as to be visible at a distance of 100 yd. during day or night. This casing may be arranged to show lights in one direction only; in two directions, either opposite or at an angle; in three, four, or more, directions, according to the plan of the intersecting roads.

The placing of the signals may be as follows:—

(*a*) Two signals act at diagonally opposite corners for 4-way lights. (This arrangement gives ample indication to all vehicles and pedestrians.)

(*b*) Four signals set at each of the four corners for two- or one-way lights. Signals should be placed at the far corners as the risk

of obstruction from vehicles is very slight. Set at near corners the signals cannot easily be seen by drivers stopped alongside.

(c) One four-way signal or post set at an island site or safety zone; or suspended above an intersection. (Four-way post signals on island sites are obviously only applicable to wide roads.)

Importance of Traffic Counts.

Before determining the system of operating a number of signals in a given street or at a single intersection, it is desirable to record in detail a census of traffic at each point, and at each intersecting road. The ordinary procedure for a traffic census recording numbers only does not furnish sufficient information to estimate the time intervals and the system of working. Observers should be instructed to record the number of vehicles at ten-minute intervals, in order to determine peak loads or maximum density. In the case of cross-roads, four traffic counts over a seven-day period would be taken of vehicles approaching the intersection, and the information obtained analysed, averaged, and plotted on graphs. Particular attention should be given to the question of weekday as against week-end traffic, also to the relative variation of the traffic during the day. On the data thus obtained it should be possible to vary the time-intervals of the signals to meet special conditions of heavy traffic at certain hours. It would be of interest to plot these diagrams on a plan of the intersection so that the proportion of timing necessary to accommodate the traffic can be seen at a glance. In Fig. 159 traffic diagrams are plotted for each road for traffic approaching the signals. It is desirable to correlate these values for opposing streets to obtain an average for the period of greatest density, and for average conditions. On the main road the density of traffic may vary along the different sections, and here again an average line should be drawn (Fig. 160).

Determination of Length of Cycle.

Experience has shown that short intervals are preferable to long intervals, and that forty to fifty seconds for a complete cycle is sufficient for peak-load conditions. In cases of exceptionally heavy traffic the period may be increased to about seventy seconds for the busiest hours of the day. In the case of the "limited progressive" system of signals, if the spacing of the signals and the streams of traffic are approximately equal, the time interval each way will also be equal. The "Amber" period varies from two to four seconds,

although in the case of wide intersections a longer period may be necessary.

In many cases a green arrow, pointing left, appears on the signal with the red, permitting traffic to "filter" (make a left turn) into the cross-stream. Prof. Blanchard, having made careful investigation on this question of "filtering," states that of 483 vehicles observed during a sixty-hour count, all exceeded a speed of 5 m.p.h. In more

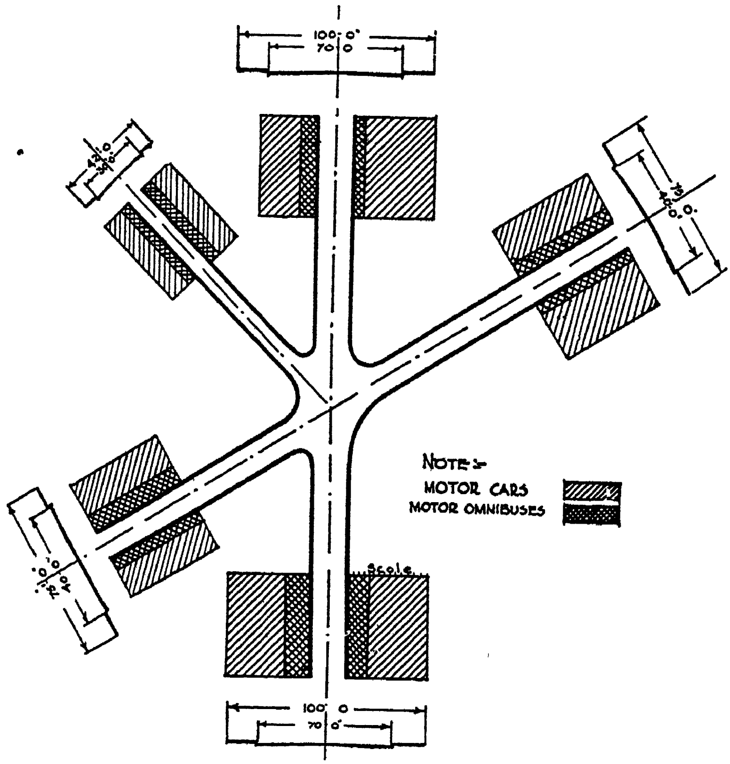

FIG. 159.—GRAPH OF TRAFFIC COUNTS AT ROAD JUNCTIONS.

than half the cases observed pedestrians were forced to jump clear, while in 22% people were hit, several seriously.

Co-ordinated Control.

This is a synchronized system whereby all signals facing the same way on a particular road show the same colour simultaneously. This involves the stopping of all traffic simultaneously, and travel is intermittent. There are several objections to this method, which encourages racing to pass as many signals as possible before the stop-

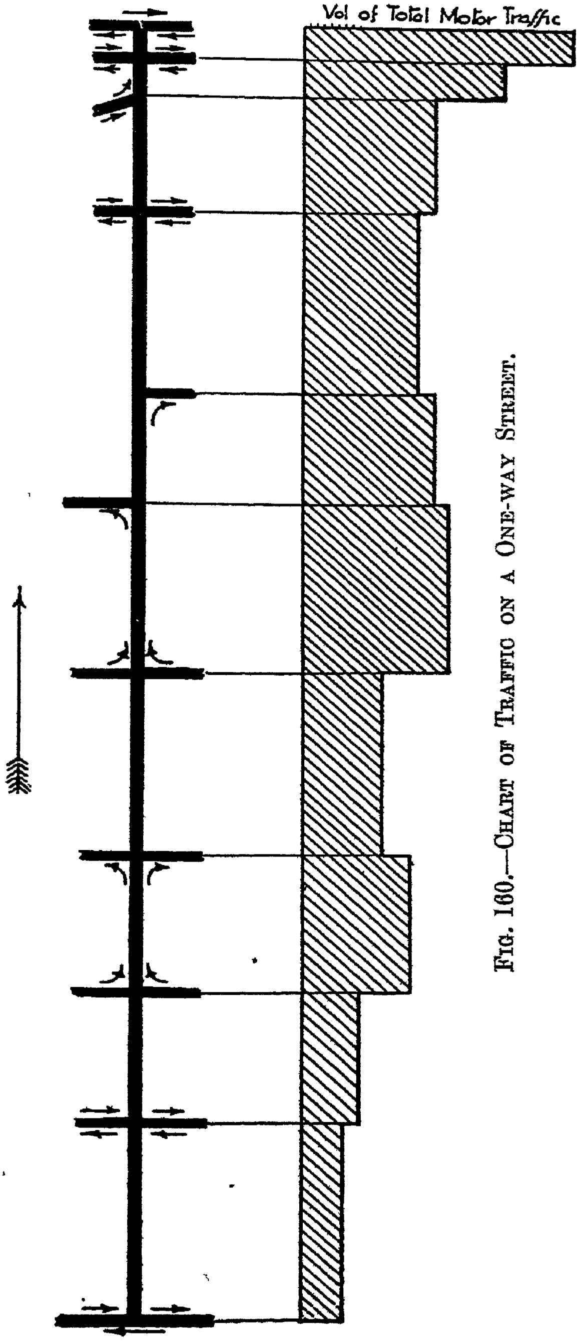

FIG. 160.—CHART OF TRAFFIC ON A ONE-WAY STREET.

page, and further, on intersections where traffic is light, the hold-up is unnecessarily long, as the timing is based upon conditions of densest traffic. The difficulty of delay due to heavy traffic intersections might be overcome by a system of one-way traffic, allowing vehicles from side-streets to make a left turn into the main stream, and crossing over at the next intersection by "filtering". To do this a road-width of at least 50 ft. between kerbs would be required. A one-way system of intersection, as adopted in large cities, enables several lanes of traffic to use the whole street width, and so pass over more quickly.

Main Road "STOP" Signs.

The use of the rule compelling the stoppage of all traffic requiring to cross or to enter a main road from light-traffic side-roads eliminates the necessity for automatic signals at those points. In other words, the main-road traffic has the right of way, and the side-road traffic, having been pulled up by a warning "Stop" sign (Fig. 161), must await a suitable opportunity to proceed. It is obvious that this rule will lessen the danger of accidents, and is an improvement on the existing method in Britain, whereby traffic emerges without stopping, sometimes without even the warning of the horn. Sooner or later it would seem that some such principle will have to be adopted here if traffic discipline is to be achieved.

The writer observed a curious "STOP" sign in Los Angeles, with light signals and "Stop" and "Go" arms, also mounted on the standard. The explanation was that the signals were used for certain peak periods only, and the "Stop" sign for the off peak periods when one of the intersecting roads was comparatively quiet.

The "Halt" sign in use in Britain is shown in Fig. 161 for purposes of comparison.

Pedestrian Signals.

Occasionally these signals are authorized for busy roads where it is desirable that pedestrians should cross; red and green lenses only are used, and except where used in connection with traffic signals, the words "DON'T CROSS" and "CROSS NOW" are required to be shown on the red and green lenses respectively.

With traffic signals, separate lamps and the same words in white letters on a black ground face across the carriage-way to guide pedestrians.

Pedestrian or "Zebra" Crossings.

Pedestrian crossings were introduced some years before the War, and they came to be adopted rather freely, so that crossings were sited on quiet roads and at points where few pedestrians required to cross.

A recent more careful selection has eliminated these points, and a new method of marking ensures that the limited number of crossings approved by the Ministry of Transport will be properly observed by both drivers and pedestrians.

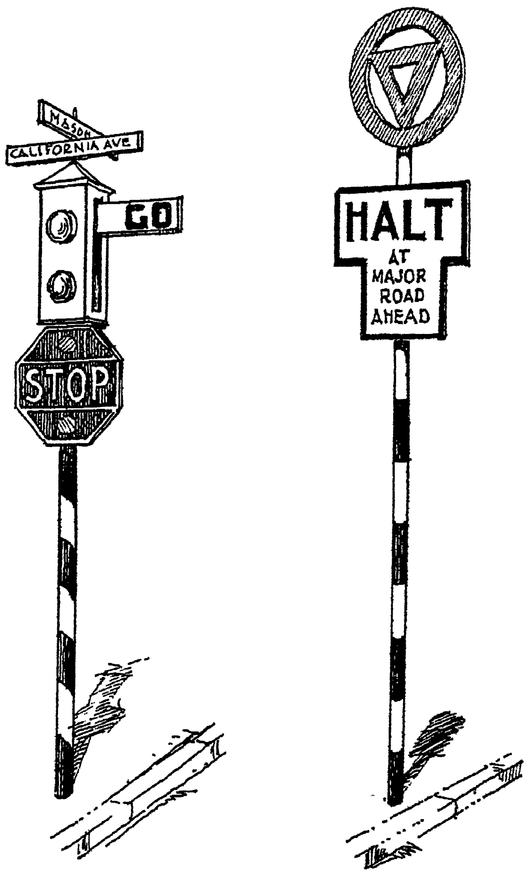

FIG. 161.—SKETCH OF "MAIN ROAD" STOP SIGN (U.S.A.) AND BRITISH "HALT" SIGN.

Generally these crossings occur on heavily trafficked roads in built-up areas which are most used by pedestrians and in connection with busy traffic circles; several important considerations govern the siting of the crossings according to Ministry regulations, and normally "waiting" traffic will not be allowed within 45 ft. of the approach side.

The crossings are defined by two lines of white silver or grey studs (square or circular) at distances apart between 8 ft. minimum and

16 ft. maximum; they are marked by alternate black and white stripes extending along the carriage-way from one line of studs to the other; the width of the stripes are between 20 in. and 28 in. Where the road surface is black, this will answer for the black stripes. The crossings are marked by the usual beacon having a yellow globe mounted at a height of between 7 and 10 ft.; these will be illuminated as "flashing beacons".

Traffic Controlled Signals.

This type of signal is now extensively used for traffic control at all kinds of intersections; where warranted by the density of traffic or other considerations; many of these are quite complicated, but, in spite of this, the system works well.

The principal feature is the rubber-shod steel pad (about 6 ft. × 1 ft.) mounted on sensitive springs and inlaid on the left-hand side of each approach to the junction. Immediately after a vehicle has passed over the detector unit or pad, the amber light operates with the red, and after a few seconds green gives the right of way; if another vehicle has established a right of way from another approach, then a waiting period is essential. When roads are busy, the timing mechanism is adjusted by the police to facilitate traffic movement from all roads to the greatest advantage. It is clear that without this the busier road would always have the right of way.

One particular use of these signals is for a comparatively quiet side road entering a busy road; a "HALT" sign would not always work, and a detector pad in the quiet road, on a suitable timing basis, enables vehicles to emerge at appropriate intervals.

"Stated Speed" Signs.

The practice of restricting traffic speeds to 30 m.p.h. in built-up areas and to have unrestricted speeds otherwise is current practice in this country; occasionally, however, one comes across a lower speed limit of, say, 15 m.p.h. in a specially difficult street or area.

It will be of interest to mention one feature of American practice in this connection. At the approach to an intersection where a lower speed is desirable for safety the figure of reduced speed is indicated on a sign at a sufficient distance from the junction to enable vehicles to slow down comfortably.

This practice occurs where main roads run through villages; at the fringe traffic slows to 25 m.p.h., then to 20, and at the intersection in the centre of the village it falls to 15 m.p.h.; proceeding outwards speed is stepped up to 20, then 25 m.p.h., then de-restricted when clear of the town. The Author has experienced this control on the

Lincoln Highway (U.S. 30), and it worked perfectly and without the slightest hold-up at the village centres.

International Signs.

One of the interesting developments for the future will be the establishment of international highways on which traffic will move quite freely from country to country. With this in view, international or common signs will be used throughout these international routes and otherwise to assist drivers to travel safely.

CHAPTER XXVII

STREET LIGHTING: LANDSCAPE TREATMENT

THE continuous improvement in the design of lanterns has contributed greatly to uniformity, efficiency, and æsthetic quality of road illumination.

Primarily, objects on a lighted road should be revealed in silhouette.

The Units of Measurement in present practice are :—

Foot Candle. The unit of intensity of illumination.

Lumen. The amount of light which falls on unit area at unit distance from one international candle.

An iso-candle chart depicts the intensity of illumination on both horizontal and vertical planes for a lantern at a fixed mounting height using a lamp emitting a stated number of lumens. These charts are a guide to the distribution of light that may be expected from a lantern.

Types of Light Distribution.

There are three main categories of light distribution from lanterns in a vertical plane :—

(*a*) non-cut-off; (*b*) semi-cut-off; and (*c*) cut-off.

The distribution from these lanterns may be specified by the downward vertical angle at which the maximum intensity of light is directed : (see Table 1).

The type of light distribution employed has a bearing on the spacing of light sources and also on the amount of glare as experienced by road-users. Glare should be minimized as much as possible, since at its worst it may affect the vision of vehicle drivers by dazzle, and at least it causes eye-strain and tiredness; it is important to note the difference of reflection under dry and under wet conditions. The aim is therefore to produce a high general road surface brightness, whilst avoiding by comparison excessive intensities from light-sources, which are usually of the tungsten and discharge lamps; of the latter there are mercury, sodium, and the development of fluorescent lighting.

Classification of Lighting Installations.

The final report of the Departmental Committee on Street Lighting, 1937, defines two groups of installations; it should be noted,

however, that the 1952 Code of Practice will probably modify these recommendations.

TABLE 1

Type of distribution.	Characteristics.	Spacing.	Downward vertical angle of max. intensity.
1. Non-cut-off	Long road surface reflections. Disadvantage: tendency to glare	Normal	80–85°
2. Semi-cut-off	Reduced glare and length of road surface reflection	„	Variable between types 1 and 3
3. Cut-off	Considerable reduction in glare (rhythmic glare only)	Reduced to avoid zebra effect	70°

Group A—Traffic Routes.

All those roads which form approaches to, or traverse important centres of population, or pass through detached built-up areas, and on which there is appreciable pedestrian traffic; these usually include Trunk and Class 1 roads.

Note.—On these roads the standard of lighting should provide an ample margin of safety for all road users without the use of headlights by motor vehicles.

Group B—Other Roads.

All other roads which the responsible Authority considers should be lighted. See Table 2 for characteristics.

TABLE 2

Lighting group.	Mounting height (ft.).	Average spacing of columns (ft.).	Light output per 100 ft. linear of roadway (lumens).
A	25	120–150	3,000–8,000
B	13–15	100–120	600–2,500

The Siting of Columns and Lanterns—Group A installation.

The spacing between light-sources varies according to the type of lantern used, and lies between 90 ft. for a cut-off installation and 150 ft. for a non-cut-off installation, the distance being the linear

measurement between the sources, measured along the centre of the road, irrespective of the arrangement of columns.

There are four general categories in which the lanterns may be arranged to suit varying widths of carriage-way, viz. :—

(a) *Staggered* (Fig. 162*a*). The spacing between light-sources in this method may be up to 150 ft.; i.e. the distance between columns on one side will be up to 300 ft.

(b) *Opposite* (Fig. 162*b*). This method is for use in areas where particularly good lighting is required, such as shopping centres; this involves high capital and maintenance costs.

(c) *Central* (Fig. 162*c*). It is common practice to employ central arrangement when cut-off lanterns are used; it is not suitable for carriage-way widths over 35 ft. wide: centre lighting is useful where there are large trees lining the road as an amenity.

(d) *Single-sided.* The single-sided arrangement should be used only on the outside of bends, and never on straight roads, as one side would appear bright and the other side relatively dark. It may be necessary to reduce the spacing between columns on bends so that an observer's line of vision does not fall on an extensive dark area (see Fig. 163): a siting gauge may be used in this connection.

Position of Light-source in Relation to the Carriage-way.

When using two or more rows of sources, as in the staggered and opposite arrangements, the distance between rows should not permit the existence of dark areas in the carriage-way. Light sources are mounted directly over the kerb when the distance between rows does not exceed 30 ft.; for roads between 30 and 42 ft. the lanterns must overhang to keep the distance between them at 30 ft. maximum. The ultimate result will depend on the type of road surface and the distribution of light.

A central row of lights, preferably placed on a central reservation, should be added to either the staggered or opposite arrangements when the width of the carriage-way exceeds 44 ft. In this case the side lanterns are usually mounted directly over the kerb, the centre row of lights being opposite those of the side rows, or arranged alternatively, or on a ratio of one to three of the side rows (see Fig. 162*e*, additional row erected on central reservation). Lighting of wide single carriage-ways (i.e. over 42 ft.) and of dual carriage-ways is shown in Figs. 162*d* and 162*e*.

Group "B" Lighting.

With a mounting height of 13–15 ft. it is not practicable to mount a lantern overhanging the kerb without the danger of impact by

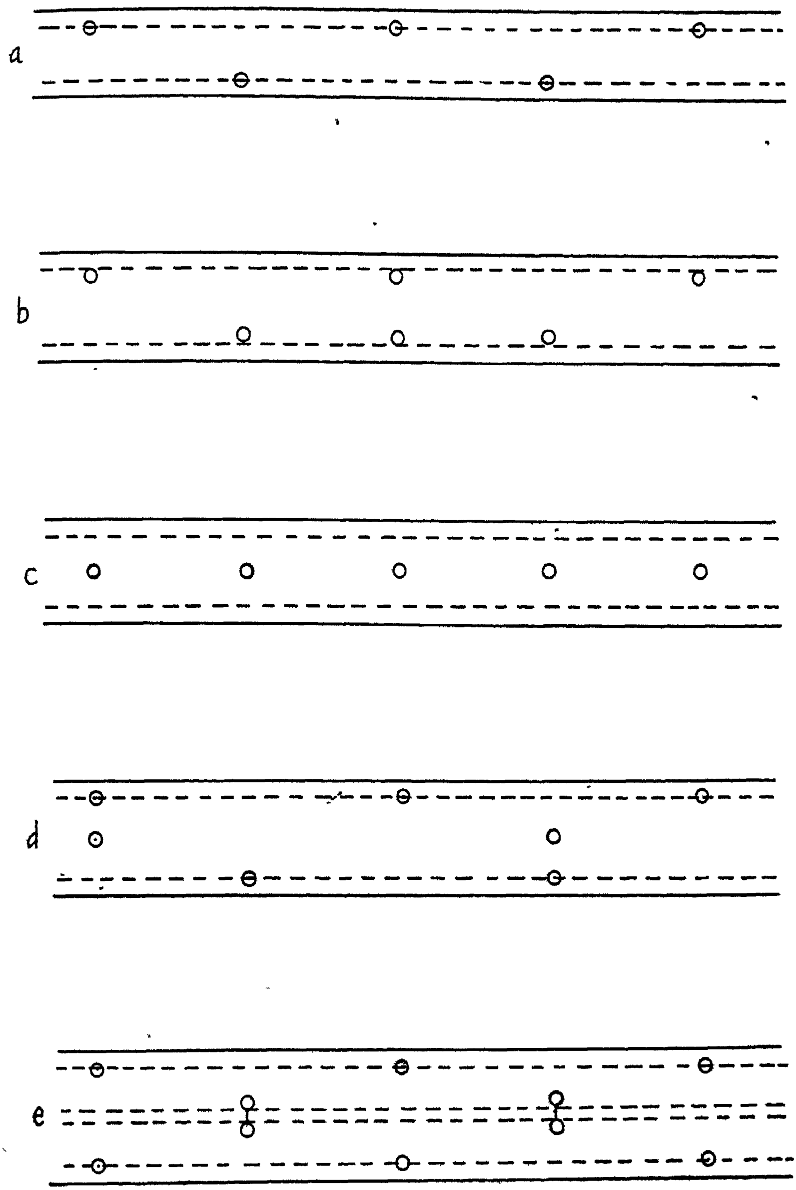

FIG. 162.—METHODS OF LIGHTING ON STRAIGHT ROADS.

a. Normal, up to 30 ft. road width.
b. Staggered, up to 42 ft. road width.
c. Central, up to 35 ft. road width.
d. Where carriageway exceeds 42 ft.
e. Opposite with central islands, over 35 ft. width.

passing tall vehicles. In some cases the columns may be better sited close to the boundary fence, and short brackets may be used to bring the light more nearly to the kerb line.

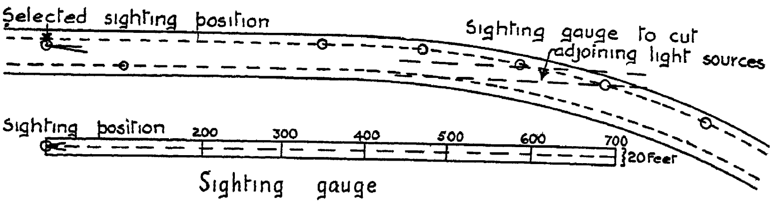

FIG. 163.—METHOD OF LIGHTING ON CURVES.

Treatment of Junctions, etc.

The siting of light-sources at junctions and intersections calls for special treatment, and local conditions will need individual consideration. The light-sources themselves should indicate, if possible, the

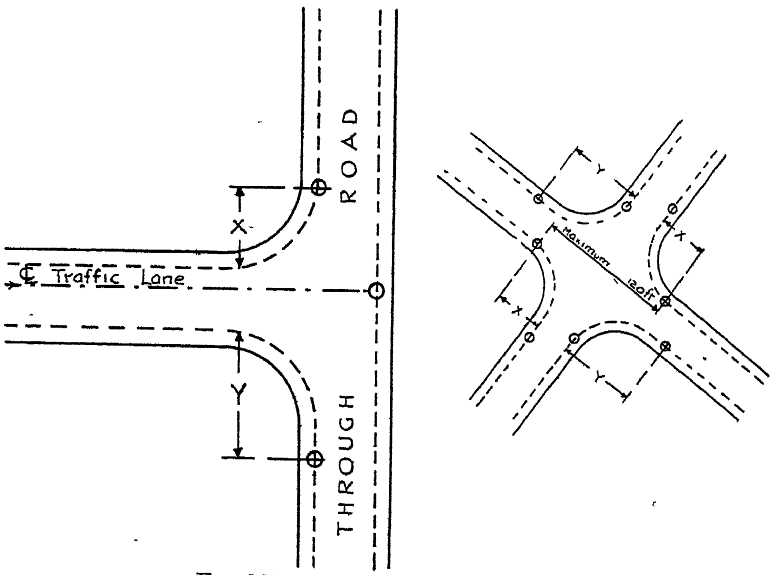

FIG. 164.—LIGHTING AT JUNCTIONS.

change of direction of a traffic route, and the fullest advantage should be taken of bright backgrounds to make the route obvious to traffic users (see Fig. 164).

The æsthetic design of lighting standards receives constant attention from the Royal Fine Art Commission, and shows a continuing improvement. Light-steel or reinforced-concrete columns are in general use; the latter have the advantage of not requiring mainten-

ance in the form of painting; simplicity of line in their design should be the first consideration, whether of steel or of concrete.

Lighting of Traffic Circles.

The question of lighting traffic circles calls for careful study according to the design conditions of the particular circle; e.g , the size of the centre island, occurrence of dual carriage-ways, etc.

Various systems of lighting have been tried, but none of them seems to be entirely satisfactory.

Lamp-standards on the centre island do not improve the appearance of the island, although in some cases there may be no alternative.

The lamps placed on the directional islands at the entrance to the circle should be about 16 ft. high; the usual " Keep Left " bollards are also necessary at such points.

Approach Signs : to Circles.

The real danger with traffic circles occurs at night from high-speed vehicles approaching the islands without sufficient warning. An interesting suggestion has been made by Mr. W. R. Stevens, for an approach sign in the form of a silhouette circle (mounted on the usual standard), which would be illuminated at night by a red neon circle. This would be reasonably discernible in fog. Such a sign would require to be placed at a considerable distance from the island.

There is a good case here for adding into the centre of the " neon " circle the reduced speeds—as suggested elsewhere—indicating progressively 30, 25, 20, and/or 15 m.p.h. (also in neon lighting) according to the design speed for the circle itself (see Fig. 165).

Landscape Treatment

One of the greatest fascinations in new town planning is the opportunity to introduce landscape features. It will require imagination and patience, since it may be several years before the real beauty shows itself.

The Engineer has been accused of designing roads as a series of parallel lines, centre margin, double carriage-way, kerbs, cycle-tracks, and foot-ways—all for utility.

Roads need not be built in this manner if there is open land at one's disposal. Even in cases where a straight road is possible, a slight bulge or bend on the centre margin of the dual carriage-way enhances the general appearance; an undulating country helps to remove the monotony of a straight road.

Tree-planting.

No modern road should be without trees; existing large trees if possible; if not, then selected saplings placed according to a plan. The preservation of existing trees in order to bring them into a

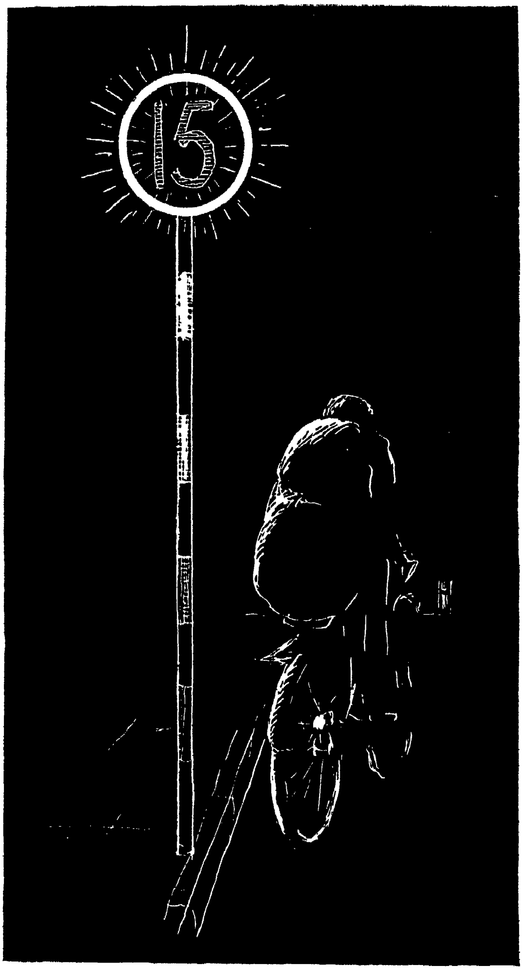

FIG. 165.—NEON CIRCLE LIGHT FOR APPROACHES TO TRAFFIC CIRCLES.

proper relationship with the road-plan calls for ingenuity and determination. It is an easy way out to cut down a large tree to maintain a particular alignment.

Planting of Saplings.

In order to avoid monotony, several varieties should be planted; limes and planes are popular, and we should not forget the horse

chestnut, the larch, and the copper beech; flowering trees and shrubs or bush-trees are attractive on wide margins; silver birch add beauty to a road, and are especially useful on the outside of a curve.

Small saplings may require to be staked and tied, but if staking can be avoided, the trees will grow stronger without this artificial support. Nature takes care of itself in these matters; the roots are strong, and pruning is not necessary.

An experiment which the Author tried out some years ago proved that the staked pruned trees on the grass margins often blew down in a gale, whereas the unstaked unpruned trees (planes) remained intact and in fact grew more rapidly in every way.

Replanting Large Trees.

It is often worth while to remove trees (not too large) to a new position; in many cases it is only a matter of a few yards which is required to give the necessary alignment. This movement may be accomplished by digging a wide and deep trench in order to "skid" the tree with the roots into the new position.

Trees of only moderate size (say thirty–forty years old) may often be replanted with success if sufficient care is taken; pruning is necessary, and it is advisable to plant the trees deep in order to provide ample moisture for the roots. Watering is absolutely essential, and if the ground is dry, then regular hosing should be done over a period of several weeks. Guy ropes should be employed for the larger trees, to steady them in all weathers until fully re-established.

There is a strong case here for the Ministry of Transport to create a special mobile department of experts with complete lifting and other equipment to move large trees where they conflict with road and planning needs.

We cannot afford to go on losing our beautiful trees and producing barren-looking new highways when there is a remedy at hand.

Planting on Traffic Islands.

This should be done with discretion; if the island is well lighted, there is no need to use head-lamps, and the question of dazzle does not arise; nor, in fact, does it occur if the island is of large diameter or if the approaches are dual, and not single carriage-ways.

If, however, it is necessary to create obscurity, shrubs, trees, or hedges may be planted, or a raised level of turf may be equally effective.

CHAPTER XXVIII

STREET FURNITURE

THE question of providing suitable equipments on the highway for the convenience of road-users is of continuous interest. The present-day trend is to secure uniformity in traffic signs and uniformity in the service rendered to the public.

Traffic signs concerning direction and warning signs must conform to the standards of the Ministry of Transport; later, these signs will conform to international standards.

All signs should be sited about 18 in. behind the kerb-line to ensure easy visibility.

Signals are increasingly becoming controlled by traffic; these should be placed in the appropriate positions and in accordance with the conditions laid down by the Departmental Committee.

Street Names; Signs.

It is the duty of every Local Authority to provide for every street name-plates in a conspicuous position; frequently these are fixed on buildings at a high level, and this is not suitable for busy town streets.

A lower level of sign will enable the motorist to observe it by head-lights in periods of darkness. The Author has used a reinforced-concrete sign with sunk letters, mounted on a reinforced-concrete frame (Fig. 166), which gives an ample bearing on its foundation, and which cannot easily be lifted out of the ground.

"House Numbers" should be placed in a position which can be seen readily from the road; numbers cast into concrete gate-posts or in panels low on walls are useful in this respect.

Guard-rails.

These fall into two categories—viz. (1) to control and separate pedestrians from the roadway in busy streets and at busy junctions; and (2) to act as a safety measure for traffic at points of extreme danger.

1. Guard-rails for pedestrians have proved invaluable in keeping roadways clear where some over-spill from the pavement would otherwise occur. They are usually fixed about 18 in. behind the kerb, and are built of tubes with or without mesh to fill in the panels; the top rail is about 3 ft. 6 in. high. Openings at

suitable points allow passengers to cross the road by the pedestrian crossing so provided; short guard-rails are invaluable where school gateways open on to busy streets

Guard-rails may be used with advantage in open unfenced country where there is a sharp change of direction. Alternatively, guide-posts up to 3 ft. high, with reflector dots, may be placed on the outside of the bend at such points.

2. Strong guard-rails for the safety of vehicles are sometimes provided on embankments which are more than 6 ft. high and which have steep slopes. Where the banks are flat, however, guard-rails may be omitted and posts substituted.

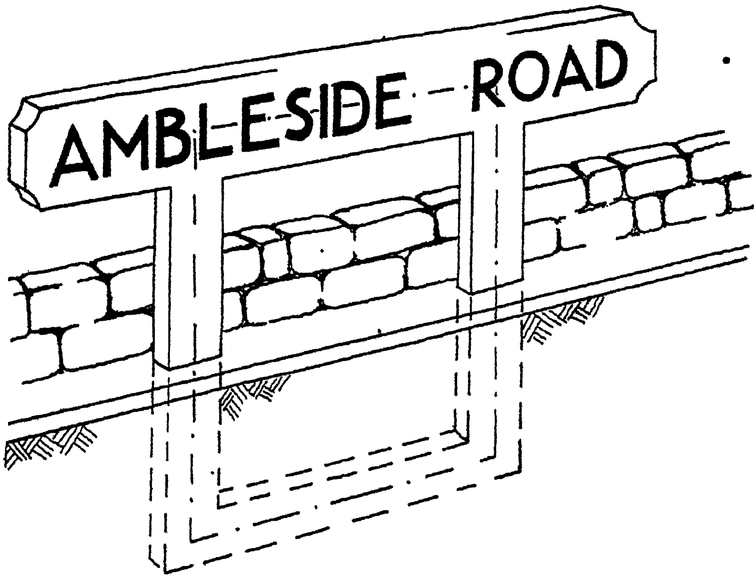

Fig. 166.—Concrete Street Sign.

Reflector Kerbs.

These are used at bends or changes of direction; when used at circles or at directional islands, their purpose is for channelizing traffic.

Bollards.

These are placed on directional islands or refuges as a prominent indication for drivers of vehicles. They should be painted white and illuminated by a white light; "Keep Left" signs will also be required. In addition, each refuge should be illuminated by a diffused light-globe on a 16-ft. standard; concrete standards for this purpose are particularly attractive.

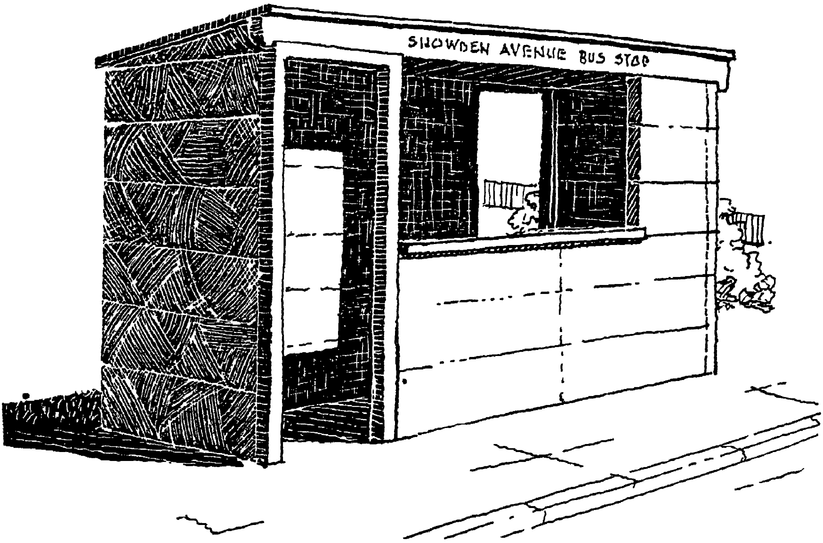

FIG. 167.—BUS SHELTER.

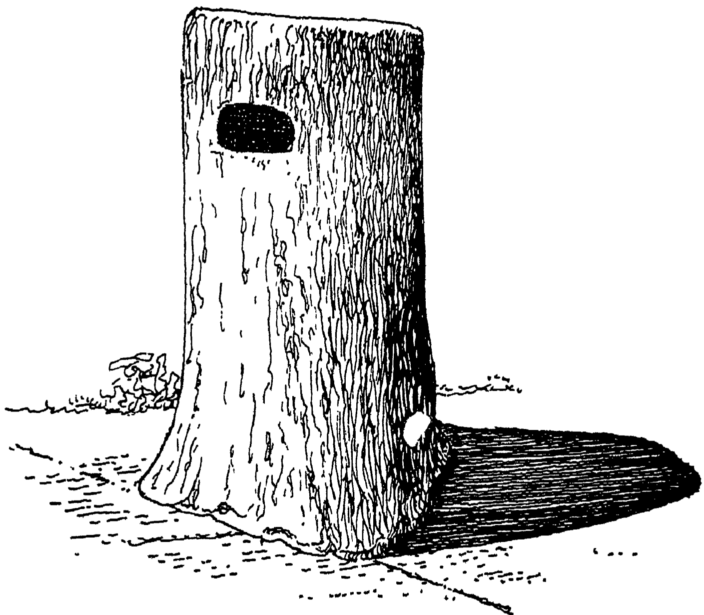

FIG. 168.—LITTER CONTAINER AND INCINERATOR IN CONCRETE, FOR HIGHWAY MARGINS AND BUS STOPS.

Seats.

There are many points in urban and in rural areas where seats may be placed with advantage. Teak or other hardwood seats are attractive; wood seats with concrete supports are simple and less expensive.

In some areas the seats should be anchored in the ground to prevent disturbance by mischievous persons.

Bus Shelters.

There are many pleasing designs of bus shelters in use throughout the country; variety according to need makes them much more interesting. They should be simple, and in many cases should allow for vision through them by ample window-space. Concrete designs are particularly attractive; it is a good plan to arrange for a street name to be placed at lintel height for the convenience of passing traffic.

An example of this type of shelter designed by the Author is shown in Fig. 167. No timber or glass is required, and maintenance is negligible.

Litter Bins.

These are an asset and help to foster civic pride. The bin illustrated in Fig. 168 is made of reinforced concrete, and is designed as an incinerator.

Telephone and Police Boxes ; Public Conveniences.

Since it is more economical and advantageous to have public conveniences above ground, it is possible to combine the building with a telephone kiosk and a police box, if this is needed.

The site will require to be carefully selected to suit the needs of the pedestrian, and with minimum interference to traffic.

General.

Many other items for the public services occur on streets, and much can be done in siting them to preserve amenity and public safety; these items include letter-boxes, stamp-machines, electricity kiosks, litter baskets, fire alarms, and, of course, traffic signs, which must be placed in the right positions to give the best service to the travelling community; concrete flower baskets (to be placed on the pavement) or baskets hanging from lamp standards provide an attractive feature of decoration for highways.

CHAPTER XXIX

PARKING FACILITIES

THESE form an important feature for the regulation of traffic in urban and city areas.

The facilities provided may be as follows :—

1. In wide streets.
2. In open spaces—which should be well lighted.
3. In one-way streets.
4. Unilateral parking in two-way streets.
5. Parking for specific or limited periods.
6. At vantage points for view purposes.
7. In buildings, in underground car parks and around public buildings.

A parking lane is usually separate and distinct from a traffic lane, and should be defined by road lines, markings on kerbs, and preferably by some different type or colour of paving; also the standard sign " P " should be used in each case except for unilateral parking, which requires special signs on each side of the road.

Local Authorities should take advantage of their powers to provide garages in towns at suitable points.

For parallel parking of cars, 7-ft. width will suffice as a minimum; for " through-traffic " roads 8 ft. is preferable, and for commercial vehicles 10 ft. is necessary.

Mass parking, such as at view-points or at special points, should be located off the highway with buffer strips between parking areas and through traffic lanes.

Parking on the highway should be forbidden near intersections; it should not be nearer than the safe " sight distance " for traffic.

Angle parking accommodates more vehicles than parallel parking, but is more dangerous for traffic using the adjoining lanes; if used it should be in a separate parking area.

With parking of two lines of cars at right angles, but facing each other and with kerbs 45 ft. apart, it should be possible to accommodate about 200 vehicles on one acre of land; due allowance would be made for access points at about every 200 ft.

The diagrams (Fig. 169) show the space required for the various arrangements of parking.

Slot Meter for Timing Parking.

In connection with car parking in busy areas of towns, a useful form of control of parking time has been secured in many parts of

the United States by use of a slot meter. A coin (of appropriate value) is placed in the slot for thirty minutes, two coins for sixty minutes, and four coins for two hours. So long as the finger is in transit and is visible, the owner is within the time limit; if not, he is liable to be fined (Fig. 170)

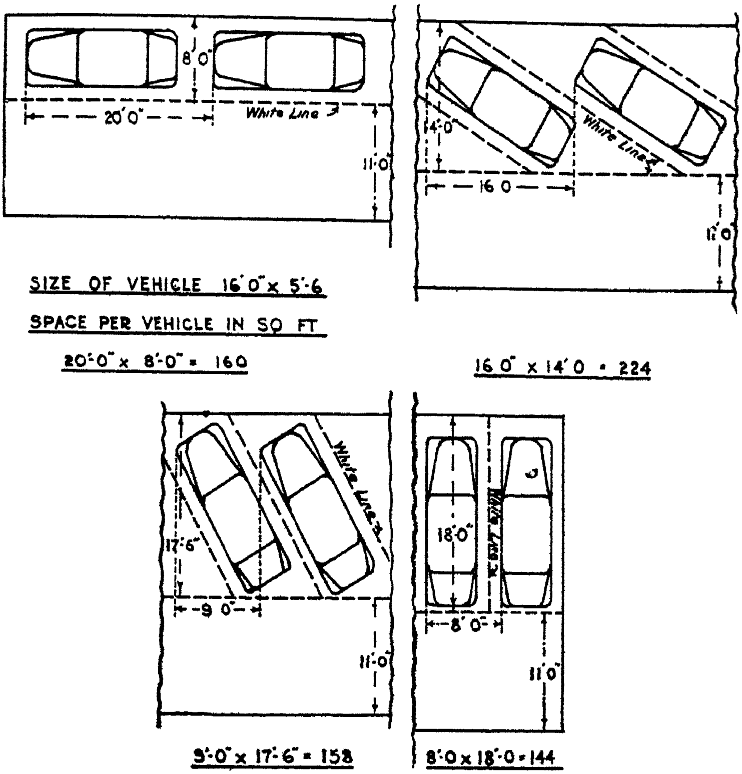

FIG. 169.—PARKING DIAGRAMS.

Omnibus Parking.

Where a public car-park is provided, accommodation for 'buses should be confined to one portion of the car-park if possible, with separate entrances and exits with footways for passengers.

Lay-by.

On busy roads, lay-bys should be constructed by a suitable set-back of the kerb, if the footway or margin is wide enough; as an alternative a 'bus stopping-place may require to be constructed off the main road, to prevent a reduction in the flow of traffic.

A lay-by should have an easy " turn-in " and " turn-out ", and

should be normally about 100 ft. in length and about 10 ft. wide (8 ft. minimum). The channel should be continued across the gap, and the usual dotted white line provided. Lay-bys on opposite sides of the road should be staggered, and if possible the paved surface should be of a different colour from that of the main road.

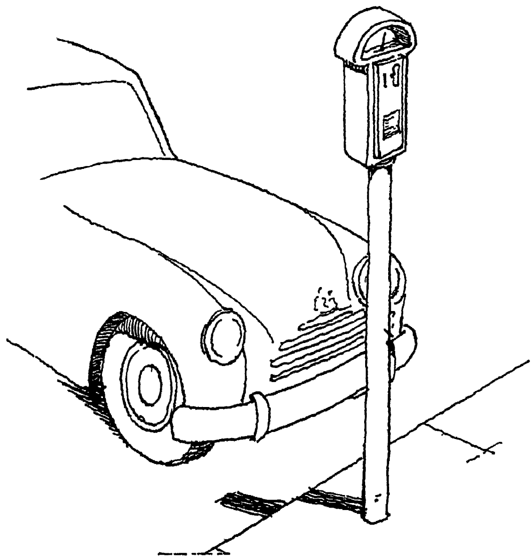

FIG. 170.—SLOT METER FOR TIMING CAR PARKING.

Parking of Cycles.

Where there is a considerable cycle traffic in built-up shopping areas or near such public places as cinemas, swimming-pools, and the like, provision should be made for the orderly parking of cycles.

This can be done on the same lines as the practice in Holland; grooves at a slant are let into the wide concrete pavement, close to the shop windows, to receive the front wheel; naturally, the system is unsuitable if the footways are narrow.

It is easy to form these grooves in concrete laid *in situ* along suitable frontages; if in addition a small iron half-ring is fixed for each groove, projecting but anchored in the concrete, the cyclist may lock the front wheel to the ring as a precaution against theft; the Author has found this method most successful in practice.

CHAPTER XXX

ROAD SYSTEMS

THE road systems of the various countries take a pattern which is generally similar, though perhaps different in detail The modern highway and rapid road transport have done more to weld communities together than any other single factor; particularly is this the case in the United States, where people now move freely from State to State.

Main roads, therefore, tend to become the concern of the State; it is essential that the whole State should carry most, if not all the financial responsibility for the trunk or national roads.

British Road System.

From the original scheme of Class I and Class II Roads which were partially financed by the Ministry of Transport, a network of trunk roads is now financed 100% from Government funds; (this expenditure is, of course, more than covered by the vehicle and petrol tax collected annually).

The classified roads, in order of importance, are as follows :—

Type of road.	Proportion of State financial responsibility.
Trunk road	100%
Class I	75%
Class II	60%
Class III	50%

All other roads are known as unclassified, supported by local funds or rates, though many of them are supported as "County Roads"; in County areas it is usual for the balance of cost on Class I, II, and III roads to be met from the County main-road rates.

By this system of finance the richer authorities in a county help to finance the poorer authorities from the common county financial pool or rate; and so the important roads are maintained to one common standard.

American Highway Classification.

Expenditure on State highway maintenance and administration has shown constantly increasing trends through the years; there

is a direct Federal expenditure on roads in National Parks, forests, and other Federal reservations.

In 1936 the classification of roads was determined as follows :—

Class.	Traffic density in vehicles per day.
A	4,000 or more
B	750–4,000
C	300–750
D	300 max.
E	200 max.
F	100 max.
G	50 max.

The classification was based on the following types of service :—

(*a*) Traffic Density. Average maximum hourly traffic of several peak days in some future year.

(*b*) Character of Traffic.

P = Passenger Type.
M = Mixed Traffic.
T = Mainly Truck Traffic.

(*c*) Assumed Design Speed. The maximum approximate uniform speed by faster group of drivers.

The financing of the various classes of roads is done under the following headings :—

1. Direct federal roads.
2. State Highways (Federal aid to State)—Primary Roads.
3. Roads financed by State, County, and Local Funds.
4. Roads financed by County and Rural Funds—Secondary Roads.
5. Local streets in incorporated places financed by Federal Aid, State, County, and Local Funds.

In addition, there are some toll roads in special areas like the district of New York.

The French system of main or National Roads is under the jurisdiction of the State; other road classes are departmental highways, vicinal, arterial, also roads of common interest and vicinal roads.

In Germany there are State or provincial roads and second-class roads in addition to the Autobahn system.

Generally, therefore, it may be said that in most countries the national or principal roads are financed by the State.

Financing Road Schemes by Loan.

It is the normal practice in this country to finance large road schemes with or without grant by way of a loan for a period of twenty years.

Local and County Authorities should not hesitate to carry out a certain amount of road construction by loan if traffic and other development warrant it; a limit of rate in the £ could be fixed for this purpose.

As the rateable value rises it will be found possible to do more work within the fixed rate, since the product of a one penny rate will rise.

It may be also that road loans taken up for schemes pre-war or otherwise will terminate from time to time, and so enable more loan schemes to be started within the limit (Fig 171).

CHAPTER XXXI

ADMINISTRATION; CONTRACTS; DIRECT LABOUR; COSTING; AND SUPERVISION

Road Works by Contract.

Contracts for road-works are usually framed to give full protection to the highway authority and to indicate to the contractor the engineering requirements and standards for the work.

The specification should be sufficiently wide to enable tenders to be invited by open competition; if proprietary articles are mentioned, the specification should be amplified by the words " or other approved material of equal quality ". Details of headings in the General Conditions of Contracts in practice from 1950 are given in Appendix II.

Direct Labour.

A considerable amount of road work, particularly maintenance and minor improvements, is carried out by highway authorities by " direct " employment of regular staff. Large authorities are better able to employ their own staffs and equipment than small authorities. Usually direct-labour employment carries with it the advantages of superannuation, holidays, and sickness with pay. It seems quite practicable in certain cases, where there are large areas of work to be done, that some incentive bonus scheme could be applied with advantage to the men and to the Authority.

Repairs to roads may be carried out by the patrol or the gang method; in the former a certain mileage is dealt with by a patrolman, with assistants if required. In the gang method a team of men with plant and vehicles will carry out more extensive operations, including re-conditioning and tar-spraying.

Haulage.

The organization and cost of road haulage of materials play an important part in the efficiency of running of a road contract; the control of operations of vehicles employed should come under the district or resident engineer, or possibly under a transport officer.

For economical running a vehicle should work the maximum mileage of loaded journeys; naturally, it is often only possible to run loaded in one direction and unloaded on the return journey; a typical example of this is the use of transit concrete-mixers; in some cases economy will result from the use of trailers.

Each driver, whether hired or departmental, should keep a log or record giving full details of all journeys. Under present conditions a lorry must carry charges for insurance, road licence, depreciation (say five to seven years "life"), petrol, oil, tyres, garage and overhead expenses.

It is often expedient to use lorries for purposes other than roadworks, in order to secure complete working days with maximum loads.

The factors affecting the cost of working are: length of haul, standing time, cost of repairs, age of vehicle, and whether loads are of full capacity or not.

Naturally, tipping vehicles (end or side tipping) are essential for road work; six-wheel vehicles have advantages over the four-wheel type; turn-tables are useful for reversing vehicles on soft ground. Mechanical loading is part of modern practice, and the "standing time" of vehicles is thus reduced to a minimum.

Unit Costs.

Unit cost records are useful to ascertain the relative and total costs of each class of work and to provide data for the assistant engineer in the examination of the progress of the work. This, in turn, also increases the sense of responsibility and public spirit of the men involved. Periodic measurements of the work should be made by the assistant engineer at least once a week.

The unit cost for a direct-labour job will be supplied by cost-clerks, after extracting the wages bill for each class of work, the area of which has been measured. The other costs, such as materials, are obtained when the unit cost of haulage is known. Upon completion, the whole of the work is measured and costs are obtained for each particular operation. In the case of contract work, the principal concern of the engineer is the progress and excellence of the work, and its completion within the specified time limit, if possible.

Measurements will be taken for this purpose, and also in order to advance payments to the contractor at reasonable intervals.

In order to determine accurately the cost of the various operations, it will be necessary to devise some system of symbols or prefix-lettering to represent these different operations, so as to simplify the recording of the actual time worked by each man in each case, and it is essential to employ a time-keeper to ensure that these entries are correctly made.

Highways Accounts

In the case of work done by Local Authorities, it is essential to have a thorough and methodical system of keeping accounts for

road-works, in order to arrive at costs quickly at any time, and also in order to present accounts to the Ministry of Transport (or the County Council where applicable) for grants towards expenditure.

The following is a description of a method of allocation for costing purposes which is known as the "slip system". A three-part code is used: (1) the Committee which incurs the expenditure; (2) the account to be charged, and (3) allocation to the sub-head of the account.

Expenditure is analysed under for main headings, i.e. (1) Wages; (2) Plant; (3) Stores; and (4) Invoices.

Wages.

The rates of pay are inserted on the time-sheets for computation of the gross wage and to make any deductions necessary; e g. Income Tax, Superannuation, National Insurance, etc. The workman's personal record is prepared on a Burrough Account Machine, recording the gross wage, deductions, and the net wage payable. An audit proof copy is prepared simultaneously with the personal record, and the totals are ascertained.

The gross wages are analysed from the time-sheets on to perforated slips, giving details of the hours, nature of work, rate, and reference to the time-sheets. The slips are sorted into code order, and the total gross wages allocated and checked with the audit proof-sheet. The weekly totals of expenditure on the various services are carried forward, and a control slip is used for posting to the costing ledger at four- or five-weekly intervals

Plant.

Haulage-sheets are prepared by the driver, showing details of the work on which the vehicle has been engaged. An hourly rate is charged for the use of the vehicle, and is reviewed at regular intervals to ensure that vehicles are not operating at a loss.

The sheets are analysed in a similar manner as wages, for posting to the costing ledger.

Stores.

Issues from stores are made only upon the presentation to the storekeeper of a stores requisition note, which is made out in triplicate and signed by an authorized person. Each note must state the nature of the job for which the materials are required. The stores-issued notes are used by the storekeeper for writing out in duplicate the perforated slips, which are forwarded to the Costing Department for pricing and coding. The original slip is coded in accordance with the heads of expenditure, and the copy is coded for

posting to the stores control ledger. The original slips are sorted in code order for posting to the costing ledger.

Where materials are issued in excess of a particular job the materials are returned to stores, and a stores credit note is issued to ensure that the credit is given to the particular job.

Invoices.

Accounts are paid at monthly intervals, a schedule of payments being prepared for approval by the Council. All invoices are certified by the Chairman of the respective Committee and head of the Department concerned.

A slip is prepared in respect of each major code, as shown on the invoice, the total of the disbursements allocated being agreed with the schedule.

Materials which are taken into store are charged to an imprest account, which is agreed with the stores control ledger.

Costing Ledger.

The control wages, plant, and stores slip, together with invoices, are entered into a sub-analysis account, which forms part of the costing ledger, at monthly intervals. The headings of the sub-analysis are arranged in accordance with the estimates, so that it is possible to ascertain at a glance the expenditure incurred against the estimate. After the expenditure has been posted to the sub-analysis, the totals shown on the control slips are machined on to a major cost-sheet, a separate sheet being kept for each main service. The major cost-sheet is totalled at the year end, and, after any transfers have been made, the figure is available for posting to the ledger.

On Cost.

The following items, which cannot be charged direct, are treated as on cost, and are apportioned at the end of the financial year by the "direct-wages" method; (*a*) National Insurance—Council contribution; (*b*) Superannuation—Council contribution; (*c*) sick and holiday pay; (*d*) tools and implements. The net cost of the Stores Depot is allocated over the various services by the "Materials Issued" method.

TECHNICAL SUPERVISION

The necessity for scientific planning and construction of roads demands an ample supply of technical supervision at all stages of the work. One or more engineering assistants may be detailed (as residents) on large schemes; on small schemes daily or regular visiting by an assistant is essential.

With the increase of speed of motor vehicles, the question of levels and changes of direction, much neglected in the past, has now become of the utmost importance. In flat districts the correct levels for gullies and channels should be given on the spot by an engineer. Surface-water drains should be laid, with boning-rod and sight-rails, in accordance with the sections, and complete records of progress, dates, subsoil and depths, and positions should be kept In fact, it is a good plan to have a record of all work done upon a road by widening, draining, or reconstruction, from time to time, as a sort of medical history of the road. Such a record would be invaluable in the preparation of the annual programme and estimates of works.

This technical supervision is a wise form of expenditure for which a return is seen by economies in subsequent work For this reason the duties of a professional assistant should be in the direction of more time spent upon works in progress than has been the case hitherto.

To ensure success in a road-building organization it is very necessary to secure the right type of assistant for the sub-chief positions, so that the "team" spirit is developed in the various branches of the department.

Facilities should be afforded for each member of the staff to make himself conversant with the general policy of the department. If necessary, written or verbal instructions should be given to all assistant engineers, inspectors, and foremen, in order that while working in independent areas they will carry out a common policy; also regular progress meetings should be held.

It is important that the Engineer or Divisional Surveyor should be furnished with an up-to-date record of accurate costing of work in progress; where possible, this data should be transferred to charts or graphs, as a guide to expenditure within the approved estimates and grants.

Finance

The question of financing road-works is one which intimately concerns the engineer, who is often called upon to advise as to the manner in which a given sum should be expended. The long-established method in vogue in this country is to raise the whole or part of the money required for road improvements and maintenance by levying a rate in the £ based on the assessment of land and property. In recent years this practice has been adjusted to exempt agricultural land, and to relieve industry of the greater part of these charges.

In county areas (excluding county boroughs) the financing of all rural and classified roads is distributed by levying a county highway

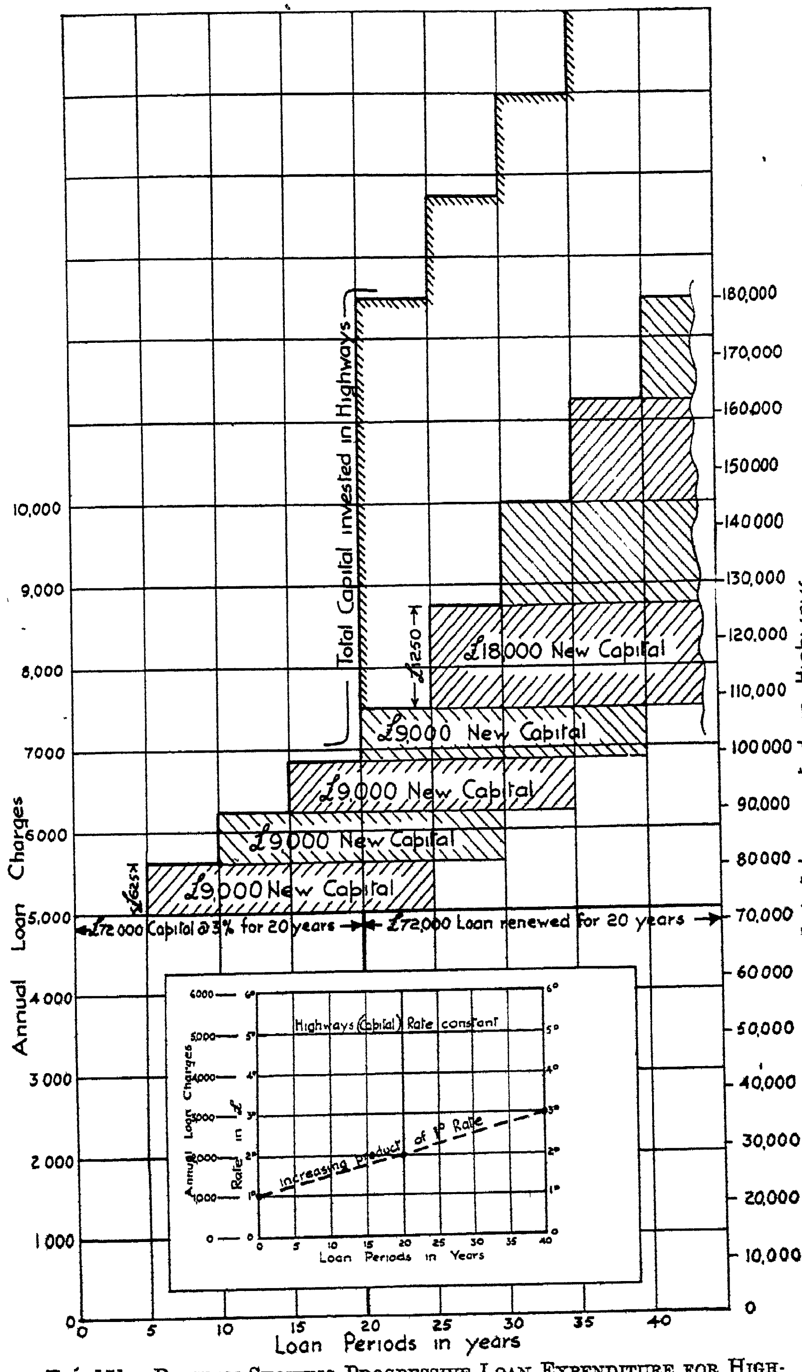

FIG. 171.—DIAGRAM SHOWING PROGRESSIVE LOAN EXPENDITURE FOR HIGHWAYS TO MAINTAIN A CONSTANT HIGHWAYS (LOCAL) RATE IN THE £.

rate over the whole county. Thus, the richer districts help to finance the poorer areas in obtaining uniformly good roads.

Financial assistance is given to the classified roads from the Road Fund, which is raised by national motor taxation. This assists further the pooling system by encouraging all districts to possess a high standard of main roads, more particularly with the object of providing for through traffic.

Road Fund grants are sometimes awarded (*a*) for road works intended to relieve unemployment and (*b*) for special schemes for widening or improving roads and bridges. Apart from this, however, it is the usual practice to finance large schemes by way of loans sanctioned by the Government. Loans are taken up at the market rate of interest for periods of repayment up to twenty-twenty-five years. As, however, more than half of the cost of any highway represents grading, drainage, structures, engineering, etc., which have an almost indefinite life, periods up to thirty years would be justified.

Where loans can be raised at low rates of interest, long-term repayment relieves the annual charge on the rates to a considerable extent.

The graph shown in Fig. 171 shows how with an increasing rateable value more capital works can be undertaken where loans are taken up for a twenty-year period, without increasing the highways rate, which remains more or less constant.

For smaller schemes, it is sometimes expedient to finance the work from revenue by distributing the cost over two or three years; as an alternative, short-period loans are desirable where they do not inflict a burden on the local rates.

Private Street Works may be financed by a seven to ten year loan, or by a fund specially created by a local authority for the purpose; thus, as the owners repay the cost of their street works, further work may be undertaken from the fund.

At the Sixth International Roads Congress held at Washington in 1930 it was recommended: (1) that, in order to meet the large financial problems, highway programmes covering a period of years should be set up well in advance and carefully budgeted; (2) that maintenance of improved highways of general use, or at least any increase over the former normal maintenance costs, should be regarded as a first charge upon the user revenues; (3) that user taxes, including licence fees and fuel taxes, should be applied exclusively for highway purposes; (4) that general taxes are a particularly appropriate source of revenue for work on local roads, including urban streets; and (5) that any assessment of abutting or other benefited property, chiefly in urban districts and their environs, should be proportional to the actual benefit to such property.

BIBLIOGRAPHY

Publications of the Ministry of Transport.

Publications of the D.S.I.R. (Road Research Board, H.M. Stationery Office).

Royal-Dawson (F. G.). *Road Curves for Safe Modern Traffic.*

—— *Elements of Curve Design for Road, Railway, etc.*

War Office. *Military Engineering,* Vol. 5, Part I. Roads.

Hickerson (T. F.). *Highway Curves and Earthwork.*

Seelye (E. E.). *Data Book for Civil Engineers.* Vol. 3. *Field Practice.*

Highway Practice, U.S.A. (Public Roads Admin., Washington).

Principles of Highway Construction as Applied to Airports, etc. (Public Roads Admin., Washington, U.S.A.).

Policies of Geometric Highways Design (A.A.S.H.O.).

German Motor Roads (Road Research Board, Tech. Paper, No. 8).

Die Reichs Autobahn (Volk & Reich Verlag). 1938.

APPENDIX I

ACTS OF PARLIAMENT OF SPECIAL IMPORTANCE FOR ROADS

THE highways of Britain are affected by many Acts of Parliament, and gradually new Acts have been passed which enable them to be brought up to modern standards. The Road Traffic Act of 1930 constituted a great step forward

It is proposed here to make brief references to five Acts which have been passed since 1930, and which are of special importance to the road engineer. These are :

The Restriction of Ribbon Development Act, 1935.
The Trunk Roads Act, 1945.
The Town and Country Planning Act, 1947.
The Special Roads Act, 1949.
The New Streets Act, 1951.

Reference is made elsewhere to the Public Utilities Street Works Act, 1950.

Included in this Appendix is a note on the working of the Private Street Works Act, 1892, by means of a simple method, a combination of " degree of benefit " and " frontage ".

THE RESTRICTION OF RIBBON DEVELOPMENT ACT, 1935

This Act was passed as a result of the rapid and uncontrolled building development along main road frontages, which took place during the period 1930–1935 and earlier.

It provides for restrictions on this kind of development along important roads, and in particular along Classified Roads; it gives power to preserve amenities, including an open view from the road, and generally to control development in the neighbourhood of roads.

Local Authorities are given powers to provide accommodation for the parking of vehicles and to require the provisions of means of entrance and egress from a new building for limiting interference with traffic along the roads adjacent thereof. Under the Act the Highway Authority may adopt for any particular road any of the standard widths laid down; the standard widths (mentioned in the first schedule) are 60, 80, 100, 120, 140 and 160 ft.

The passing of the Town and Country Planning Act, 1947, has now given much wider powers for all aspects of Town Planning than obtained in 1935; nevertheless, some of the provisions, such as the

preservation of amenities, are easy to operate under the Act and the importance of the powers under the Act should be borne in mind in connection with all road development and improvements.

Trunk Roads Act, 1945

The Trunk Roads Act of 1936 created a network of trunk roads throughout the country which were maintained out of the Road Fund. The Trunk Roads Act of 1945 conferred additional powers relating to one-way roads, cycle-tracks, and footpaths; authority was also given to the construction of roads in connection with a junction of a trunk road and to stop up any road junction in the interests of public safety and, further, to acquire land within 220 ft. of the middle of the road for the purpose of preserving amenities.

The main object of the Bill is to supplement the system of routes for through traffic by adding other routes, "including routes within areas hitherto excluded from the trunk roads system", forming an inter-connecting system of principal routes between various parts of the country.

This Act affords an excellent opportunity to build cycle roads and footpaths which need not be adjacent to the carriage-way; they may be built within a limit of 220 ft. of the centre of the road; it is unfortunate, perhaps, that the limit is not even greater. Nevertheless there is here a great opportunity to build attractively for segregation and safety in the best possible manner, and it is hoped that engineers will take the fullest advantage of this.

The Act also confers upon the Minister powers to construct bridges and tunnels over and under navigable waters.

Town and Country Planning Act, 1947

This Act is undoubtedly the most comprehensive legislation ever placed on the Statute Book for the purpose of controlling the planning and development of the country.

Powers are given to authorize the construction and financing of new roads, to construct and improve private streets, and to stop up and divert highways.

One of the most important items in the Act is the power to control advertisements, and regulations have now been issued for guidance in this matter; indiscriminate advertising along the frontages of main roads, as occurs in America, will no longer be possible.

Another section deals with the preservation of trees and woodlands so that "Tree Preservation Orders" may be made by the Ministry (*a*) to prohibit lopping or destruction, (*b*) to secure replanting, and (*c*) to grant compensation, if justified, where any consent is refused.

The wide powers contained in the Act confer great potential benefits for highway engineering; the operation of the various sections in the light of experience merits the closest attention, and makes it incumbent on the highway engineer to acquaint himself fully with all the sections and their operation in the light of experience.

The Special Roads Act, 1949

This Act is designed to give power to provide roads which are restricted to particular classes of traffic only; in this respect it is a departure from the principle that public highways are available without restriction to all persons and classes of traffic.

Schemes may be provided by the Minister of Transport or by the Local Highway Authority in conjunction with the Ministry.

These special roads are intended to be motor roads similar to the German autobahn or the express highways in America. In the Act there is power to provide special roads for horse-drawn vehicles, pedal cycles, and animals; part of a motor road may be used in this way by suitable provision.

Naturally powers are given for the stopping-up or diversion of access roads (this includes roads giving access from the special roads to private premises) and to provide alternative roads in place of the "stopped-up" roads.

There are restrictions upon the laying of mains, including sewers, with a saving clause for the powers of the Postmaster-General in relation to telegraph lines; there are also a number of amendments to the Trunk Roads Act of 1936 and of 1946.

New Streets Act, 1951

Where new buildings are likely to be erected in new private streets, the sum estimated to complete the street works is paid in advance to the Highway Authority or some other security provided, under this Act.

The Act gives power to Highway Authorities to adopt this procedure; it also enables frontagers to call upon the Local Authority, when development has reached a certain stage, to carry out the street works, and for the street to be adopted as a public highway repairable by the "inhabitants at large".

One advantage of this method of "payment in advance" of building is that purchasers of the houses are freed from the uncertainty as to the ultimate cost and time of carrying out the street works; under this scheme, too, it is possible (and sometimes desirable) for a developer to make an equal street charge against all houses, even though the frontages are variable.

Note on Private Street Works Act, 1892

The making up of unpaved private streets requires a procedure which is laid down in the Public Health Act, 1875, and the Private Street Works (Adoptive) Act, 1892. Under the former, notices are served upon the owners—i.e. the frontagers—by the Local Authority, calling upon them to do the work of paving, etc., according to plans, sections, and specification: failure to comply entitled the Local Authority to do the work and recover the cost on a basis of frontage.

In the Act of 1892 a provisional apportionment is served upon the frontagers, who may object within a month; usually the objections are dealt with satisfactorily and the work proceeds. Under this Act the cost may be apportioned by "degree of benefit", instead of entirely pro-rata to frontage method, and it is in cases like this that objections arise. It is difficult to convince a frontager that he should pay at a greater rate than that required by frontage measurement.

There is something to be said for the longer frontages bearing a greater charge than the short frontages, since there is a better amenity value with the former

The Author has adopted with satisfactory results a method which embodies both the frontage and the "degree-of-benefit" method. Half the total cost of the work is apportioned on a frontage basis and half on an equal basis; i.e. each separate frontager pays an equal charge for half the total cost. Thus the narrow frontages pay a little more and the wide frontages pay a little less than if the apportionment were on a frontage basis only. The scheme works well and it has generally been accepted as a fair basis.

In the case of a complete estate, private or municipal, it is easy to carry out the street works and to make an equal charge against each house, whether corner house or one with narrow frontage, and irrespective of whether some streets are of a full bye-law width and others of some lower width (see New Streets Act, 1951).

It is understood, of course, that any street on an estate which is over bye-law width is a town planning road; the cost of paving the additional width must be borne by the Local Authority.

Appendix II

The following is an Index of the General Conditions of Contract, issued in January 1950, which have been revised by the Institution of Civil Engineers jointly with the Association of Consulting Engineers and the Federation of Civil Engineering Contractors, and are in their revised form approved and recommended by these bodies for general use.

INDEX TO GENERAL CONDITIONS OF CONTRACT

Clause	Definitions and Interpretation
12 (5)	Return of Costs.
(6)	Reference to Arbitrator
(7)	Further Notices.
13	Work to be to Satisfaction of Engineer.
14	Programme to be Furnished.
15	Contractor's Superintendence.
16	Removal of Workmen.
17	Setting out
18	Boreholes and Exploratory Excavation.
19	Watching and Lighting.
20 (1)	Care of Works.
(2)	Accepted Risks.
21	Insurance of Works, etc.
22 (1)	Damage to Persons and Property.
(2)	Indemnity by Employer.
23 (1)	Third Party Insurance.
(2)	Minimum Amount of Third Party Insurance.
24 (1)	Accident or Injury to Workmen.
(2)	Insurance Against Accident, etc , to Workmen.
25	Remedy on Contractor's Failure to Insure.
26	Giving of Notices and Payment of Fees.
27	Fossils, etc.
28	Patent Rights and Royalties.
29	Interference with Traffic and Adjoining Properties.
30 (1)	Extraordinary Traffic.
(2)	Special Loads.
(3)	Settlement of Extraordinary Traffic Claims.
31	Facilities for Other Contractors.
32	Supply of Plant Material and Labour.
33	Clearance of Site on Completion.

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34 (1)	Rates of Wages and Hours and Conditions of Labour.
(2)	Certificate of Compliance with Conditions of Clause.
(3)	Trade Union Membership.
(4)	Copy of Clause to be Displayed.
(5)	Observance by Sub-Contractors.
(6)	Civil Engineering Construction Conciliation Board.
35	Returns of Labour, etc.

WORK MATERIALS AND PLANT.

36 (1)	Quality of Materials and Workmanship and Tests.
(2)	Cost of Samples.

Clause	*Definitions and Interpretation*
36 (3)	Cost of Tests.
(4)	Cost of Tests not Provided for, etc.
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38 (1)	Examination of Work before Covering up.
(2)	Uncovering and Making Openings.
39 (1)	Removal of Improper Work and Materials.
(2)	Default of Contractor in Compliance.
40 (1)	Suspension of Work.
(2)	Suspension Lasting more than Three Months.

COMMENCEMENT TIME AND DELAYS.

41	Commencement of Works.
42 (1)	Possession of Site.
(2)	Wayleaves, etc.
43	Time for Completion.
44	Extension of Time for Completion.
45	No Night or Sunday Work.
46	Rate of Progress.
47 (1)	Liquidated Damages for Delay.
(2)	Reduction of Liquidated Damages.
48	Certificate of Completion of Works.

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49 (1)	Definition of Period of Maintenance.
(2)	Execution of Work of Repair, etc.
(3)	Cost of Execution of Work of Repair, etc.
(4)	Remedy on Contractor's Failure to Carry Out Work Required.
(5)	Temporary Reinstatement.
50	Contractor to Search.

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51 (1)	Variations.
(2)	Orders for Variations to be in Writing.
52 (1)	Valuation of Variations.
(2)	Power to Engineer to Fix Rates.
(3)	Daywork.
(4)	Claims.

PROPERTY IN MATERIALS AND PLANT.

53 (1)	Plant, etc., the Property of the Employer.
(2)	Revesting of Plant, etc.

Appendix III

TABLE I

Quantity of Mixing Water Required for Concrete.

Gallons of water per sack (1 cu. ft.) of cement, using aggregates of different fineness modulus.

Misc. cement. Agg. coy. vol.	1·50	2·00	2·50	3·00	3·50	4·00	4·50	5·00	5·50	6·00	6·50	7·00
					U.S. Gall							
					Relative Consistency—(R) = 1·00.							
1–12	23·5	21 4	19·5	17·8	16 4	15·2	13·9	12·9	12 0	11·1	10·4	9·8
1–9	18·1	16 7	15·2	14·0	12 9	12·0	11·0	10·2	9·6	9·0	8·4	7·9
1–7	14·7	13·5	12 3	11·4	10·6	9·9	9·1	8·6	8·0	7·6	7 2	6·7
1–6	13·0	12·0	11·0	10·2	9·5	8·9	8·3	7·7	7·3	6·8	6·5	6·2
1–5	11·2	10·4	9·5	8·9	8·3	7·8	7·3	6·9	6·4	6·1	5·8	5·5
1–4	9·5	8·9	8·2	7·7	7·2	6 8	6·3	6·0	5·7	5·4	5·2	5·0
1–3	7·8	7·2	6·7	6·3	6·0	5·7	5·4	5·1	4·9	4·6	4·5	4·3
1–2	6·0	5·7	5·4	5·1	4·9	4·7	4·5	4 3	4·1	4·0	3·9	3·8
1–1	4·3	4·1	3·9	3·8	3·7	3·6	3·5	3·4	3·3	3·2	3·2	3·1
					Relative Consistency—(R) = 1·10.							
1–12	25·8	23·6	21·4	19·6	18·1	16·7	15 3	14·2	13·2	12·2	11·4	10·8
1–9	19·9	18·4	16·7	15 4	14·2	13·2	12·1	11·2	10·6	9·9	9·2	8·7
1–7	16·2	14·9	13·5	12·5	11·7	10·9	10·0	9·5	8·8	8·4	7·9	7·4
1–6	14·3	13·2	12·1	11·2	10·5	9·8	9·1	8·5	8 0	7·5	7·2	6·8
1–5	12·3	11·4	10·5	9·8	9·1	8·6	8·0	7·6	7 0	6·7	6·4	6·1
1–4	10·5	9·8	9·0	8·5	7·9	7·5	6·9	6 6	6·3	5 9	5·7	5·5
1–3	8·6	7·9	7·4	6·9	6·6	6·3	5·9	5·6	5·4	5·1	5·0	4·7
1–2	6·6	6·3	5·9	5·6	5·4	5·2	5·0	4·7	4·5	4·4	4·3	4·2
1–1	4·7	4·5	4·3	4·2	4·1	4·0	3·9	3·7	3·6	3·5	3·5	3·4
					Relative Consistency—(R) = 1·25.							
1–12	29·4	26·8	24·4	22·2	20·5	19 0	17·4	16·1	15·0	13·9	13·0	12·3
1–9	22·6	20·9	19·0	17·5	16·0	15·0	13·8	12·7	12·0	11·2	10·5	9·9
1–7	18·4	16·9	15·4	14·3	13 2	12 4	11·4	10·7	10·0	9·5	9·0	8·4
1–6	16·3	15·0	13·8	12·8	11·9	11·4	10·4	9·6	9·1	8·5	8·1	7·7
1–5	14·0	13·0	11·9	11·1	10·4	9·8	9·1	8·6	8·0	7·6	7·2	6·9
1–4	11·9	11·1	10·2	9·6	9·0	8·5	7·9	7·5	7·1	6·8	6·5	6·2
1–3	9 8	9·0	8·4	7 9	7·5	7·1	6·8	6·4	6·1	5·8	5·6	5·4
1–2	7·5	7·1	6·8	6·4	6·1	5·9	5·6	5·4	5·1	5·0	4·9	4·8
1–1	5·4	5·1	4·9	4·8	4·6	4·5	4·4	4·3	4·1	4·0	4·0	3·9

Note.—The U.S. gallon is equal to 0·833 of a British gallon,

TABLE II

Professor Abram's Table of Proportion and Quantities for One Cubic Yard of Concrete

Based upon laboratory investigations using approved materials. Compressive strength, twenty-eight days with workable plasticity, 6 by 12-inch cylinders, 3000 pounds per square inch.

Size. Coarse aggregate. Inches	Cement in barrels. Aggregates in cubic yards	Fine aggregate screen openings per inch														
		0—28			0—14			0—8			0—4			0—⅜ in		
		Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement.	Fine	Coarse
No. 4 screen to ¾	Proportions Quantities	1 1 96	1 3 0·37	2 4 0 69	1 1 85	1·6 0·44	2 4 0 66	1 1 82	1·8 0 48	2·3 0 62	1 1 75	2·0 0·52	2·3 0 59	1 1 79	2·7 0 72	1 5 0 40
No. 4 screen to 1	P Q.	1 1 90	1·3 0·36	2 7 0 76	1 1 77	1 6 0 42	2 6 0·68	1 1 72	1 8 0 46	2 6 0 66	1 1 67	2·0 0 50	2 5 0 62	1 1 72	2 6 0 66	1 8 0 46
No. 4 screen to 1½	P. Q.	1 1 82	1 2 0·32	3·1 0 84	1 1 68	1 6 0 40	3 2 0 79	1 1 63	1 7 0·41	3 1 0 75	1 1 61	2 0 0 47	3 0 0 72	1 1 62	2 4 0 57	2 4 0 57
No. 4 screen to 2	P. Q.	1 1 75	1·2 0 31	3 5 0·90	1 1·63	1 5 0 36	3 5 0·85	1 1 55	1 6 0 36	3 7 0 85	1 1 52	1 9 0 43	3 6 0·81	1 1 53	2 2 0 50	3 1 0·70
No. 4 screen to 2½	P Q.	1 1·72	1·1 0·28	3·8 0·97	1 1·58	1·4 0·33	3 9 0·91	1 1·51	1 6 0·35	4·0 0·89	1 1·49	1 8 0·40	4 0 0·88	1 1·50	2 1 0·46	3 5 0 78
No. 4 screen to 3	P. Q.	1 1 69	1 1 0 28	3 9 0 97	1 1·58	1 4 0·33	4·1 0 97	1 1·49	1 5 0 33	4 1 0 90	1 1 49	1 7 0·37	4 1 0 90	1 1 49	2·0 0 44	3 7 0 81
No. ⅜ screen to ¾	P Q.	1 1·96	1 3 0·37	2 3 0·67	1 1 85	1 7 0 46	2 3 0·63	1 1 82	1 9 0 51	2 3 0 62	1 1 75	2 2 0 57	2 2 0 57	1 1·79	2 8 0 75	1 4 0 37
No. ⅜ screen to 1	P. Q.	1 1 90	1·3 0 36	2·6 0 74	1 1·77	1·7 0 44	2 6 0 68	1 1 72	1 9 0 48	2 5 0 64	1 1 67	2·2 0 54	2 4 0 59	1 1 72	2·7 0 68	1·7 0 43
No. ⅜ screen to 1½	P. Q.	1 1 82	1·3 0·35	3·0 0 80	1 1·58	1 7 0 43	3 0 0 75	1 1 63	1 9 0 46	3 0 0 73	1 1 61	2 1 0·50	2 9 0 68	1 1 62	2 6 0 63	2 2 0 53
No. ⅜ screen to 2	P. Q.	1 1 75	1 3 0 34	3 3 0 86	1 1 63	1 7 0 41	3 4 0·83	1 1 55	1·8 0 42	3 5 0 80	1 1·52	2 0 0 45	3 4 0 77	1 1 53	2 4 0 62	2 9 0 66
No. ⅜ screen to 2½	P. Q.	1 1·72	1·3 0·33	3·7 0·95	1 1·58	1·6 0·37	3·7 0·87	1 1·51	1 7 0 37	3 9 0 87	1 1 49	2 0 0 44	3 8 0 84	1 1·50	2 3 0 51	3 3 0 74
No. ⅜ screen to 3	P. Q.	1·0 1·68	1·2 0·30	3·8 0·95	1 1·58	1·6 0·37	3 9 0·91	1 1 49	1·7 0·37	4 0 0·88	1 1 49	1 9 0 42	4 0 0 88	1 1·49	2·2 0 48	3 5 0 77

No. ½ screen to ¾	P. Q.	1·0 1·96	1·5 0·44	2·3 0·67	1 1·85	1·9 0·52	2·2 0·61	1 1·82	2·1 0·56	2·2 0·59	1 1·75	2·3 0·59	2·1 0·54	1 1·79	2·8 0·75	1·3 0·31
No. ½ screen to 1	P. Q.	1 1·90	1·5 0·42	2·5 0·70	1 1·77	1·9 0·50	2·5 0·66	1 1·72	2·1 0·53	2·4 0·61	1 1·67	2·3 0·57	2·4 0·59	1 1·72	2·8 0·72	1·6 0·41
No. ½ screen to 1½	P. Q.	1 1·82	1·4 0·37	2·8 0·75	1 1·66	1·9 0·47	2·9 0·73	1 1·63	2·1 0·51	2·9 0·69	1 1·61	2·2 0·52	2·8 0·66	1 1·62	2·7 0·65	2·1 0·51
No. ½ screen to 2	P. Q	1 1·75	1·4 0·36	3·3 0·86	1 1·63	1·9 0·46	3·3 0·79	1 1·55	2·0 0·46	3·4 0·78	1 1·52	2·2 0·50	3·3 0·74	1 1·53	2·7 0·62	2·7 0·62
No. ½ screen to 2½	P. Q.	1 1·72	1·4 0·35	3·6 0·91	1 1·58	1·8 0·43	3·6 0·85	1 1·51	1·9 0·42	3·7 0·83	1 1·49	2·1 0·46	3·7 0·81	1 1·50	2·6 0·59	3·1 0·69
No. ½ screen to 3	P. Q.	1 1·68	1·3 0·33	3·7 0·92	1 1·58	1·8 0·42	3·8 0·89	1 1·49	1·8 0·40	3·9 0·86	1 1·49	2·1 0·46	4·0 0·88	1 1·49	2·4 0·53	3·3 0·63
No. ¾ screen to 1	P. Q.	1 1·90	1·7 0·48	2·4 0·68	1 1·77	2·1 0·55	2·4 0·63	1 1·72	2·1 0·61	2·1 0·53	1 1·67	2·6 0·64	2·2 0·55	1 1·72	3·1 0·79	1·5 0·39
No. ¾ screen to 1½	P. Q.	1 1·82	1·7 0·46	2·7 0·73	1 1·79	2·0 0·50	2·8 0·70	1 1·63	2·3 0·55	2·7 0·65	1 1·61	2·5 0·59	2·7 0·64	1 1·62	3·0 0·73	2·0 0·18
No. ¾ screen to 2	P. Q.	1 1·75	1·7 0·44	3·1 0·80	1 1·63	2·0 0·48	3·1 0·75	1 1·55	2·3 0·53	3·1 0·72	1 1·52	2·5 0·56	3·0 0·67	1 1·53	3·0 0·68	2·4 0·55
No. ¾ screen to 2½	P. Q.	1 1·72	1·7 0·43	3·3 0·84	1 1·63	2·0 0·47	3·5 0·83	1 1·51	2·3 0·52	3·4 0·76	1 1·49	2·4 0·53	3·4 0·75	1 1·50	2·9 0·64	2·8 0·62
No. ¾ screen to 3	P. Q.	1 1·68	1·7 0·43	3·5 0·88	1 1·58	2·0 0·17	3·7 0·87	1 1·49	2·3 0·51	3·7 0·81	1 1·49	2·1 0·53	3·6 0·79	1 1·49	2·8 0·62	3·1 0·68
No. 1 screen to 1½	P. Q.	1 1·82	1·7 0·46	2·8 0·75	1 1·68	2·0 0·50	2·9 0·73	1 1·63	2·3 0·55	2·7 0·65	1 1·61	2·6 0·62	2·6 0·62	1 1·62	3·1 0·75	2·0 0·18
No. 1 screen to 2	P. Q.	1 1·75	1·5 0·39	3·2 0·83	1 1·63	1·9 0·46	3·5 0·85	1 1·58	2·2 0·51	3·3 0·76	1 1·52	2·4 0·54	3·3 0·74	1 1·53	3·0 0·68	2·6 0·59
No. 1 screen to 2½	P. Q.	1 1·72	1·4 0·35	3·4 0·86	1 1·58	1·9 0·45	3·8 0·89	1 1·51	2·0 0·14	3·7 0·83	1 1·49	2·3 0·51	3·7 0·81	1 1·50	2·7 0·59	3·1 0·69
No. 1 screen to 3	P. Q.	1 1·67	1·3 0·33	3·6 0·90	1 1·58	1·8 0·42	4·0 0·94	1 1·49	2·0 0·41	3·9 0·86	1 1·49	2·2 0·48	3·9 0·86	1 1·49	2·7 0·59	3·3 0·73

P = Proportions of coarse and fine aggregates to cement.

Q = Volume in cu. yds. coarse and fine aggregates to number of barrels of cement.

Note.—One barrel of cement = 4 cub. ft.

APPENDIX IV

BRITISH STANDARDS FOR CEMENT

THE following data are summarized from the various British Standards for cement, i.e., B.S. 12 for ordinary Portland and rapid-hardening Portland cements, B.S. 146 for Portland blast furnace cement, and B.S. 915 for high alumina cement.

1. *Proportions* (B.S. 146 only).

Portland blast furnace cement to contain not more than 65% slag by weight.

2. *Fineness.*

(100 gm. of cement sieved for fifteen minutes on No. 170 B.S. sieve)

Type of cement.	B.S. No.	Retained on No. 170 sieve.
Ordinary Portland	12	Not more than 10% by weight
Rapid-hardening	12	,, ,, 5% ,,
Blast furnace	146	,, ,, 10% ,,
High alumina	915	,, ,, 8% ,,

3. *Chemical Composition.*

(*a*) Ordinary and rapid-hardening Portland (B.S. 12) and Portland blast furnace (B.S. 146).

MAXIMUM PERCENTAGES BY WEIGHT

	Ordinary and rapid-hardening.	Portland blast furnace.
Insoluble residue	1·0%	1·0%
Magnesia	4·0%	5·0%
Sulphur:		
As SO_3	2·75%	2·0%
As sulphide	—	1·2%
Loss on ignition:		
Temperate climates	3·0%	3·0%
Hot climates	4·0%	4·0%

Percentage of lime (after deduction of that necessary to combine with the SO_3 present) shall not be more than 2·8 times the percentage

of silica plus 1·2 times the percentage of alumina plus 0·65 time th(percentage of iron oxide, nor shall it be less than two-thirds tha amount. The ratio of the percentage of iron oxide to that of alu mina shall not exceed 1·5

(*b*) High alumina cement (B.S. 915). Total alumina to be no less than 32% by weight. Ratio of percentage by weight of alumin: to lime to be not less than 0·85 nor more than 1·3.

4. *Tensile Strength.*

Tensile strength of standard 1 : 3 mortar briquettes in lb./sq. in All cements to show an increase in strength with age.

Cement.	1 day.	3 days.	7 days.
Ordinary Portland . . .	—	300	375
Rapid-hardening . . .	300	450	—
Blast furnace	—	300	375
High alumina	—	Not included in B.S.	

5. *Compressive Strength.*

Strength of 1 : 3 standard mortar cubes in lb./sq. in. water-cement ratio 0·40 by weight. All cements to show an increase ir strength with age.

Cement.	1 day.	3 days.	7 days.
Ordinary Portland . . .	—	1,600	2,500
Rapid-hardening . . .	1,600	3,500	—
Blast furnace . . .	—	1,600	2,500
High alumina . .	6,000	7,000	—

6. *Setting Times.*

Cement.	Initial set not less than :	Final set not more more than :
Ordinary Portland .	30 minutes	10 hours
Rapid-hardening .	”	”
Quick setting [1] . .	5 minutes	30 minutes
Blast furnace . .	30 minutes	10 hours
High alumina . .	Not less than 2 hours nor more than 6 hours	Not more than 2 hours after initial set

[1] "Quick setting" cement may be either ordinary Portland, rapid-hardenin or blast furnace. It does not necessarily harden rapidly.

7. *Soundness* (*Le Chatelier Test*).

Cement.	Expansion after 3 hour's boiling to be not more than :
Ordinary Portland . .	10 mm. (or 5 mm. after 7 days' aeration)
Rapid-hardening . .	10 mm. (or 5 mm. after 7 days' aeration)
Blast furnace . . .	10 mm. (or 5 mm. after 7 days' aeration)
High alumina . . .	1 mm.

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